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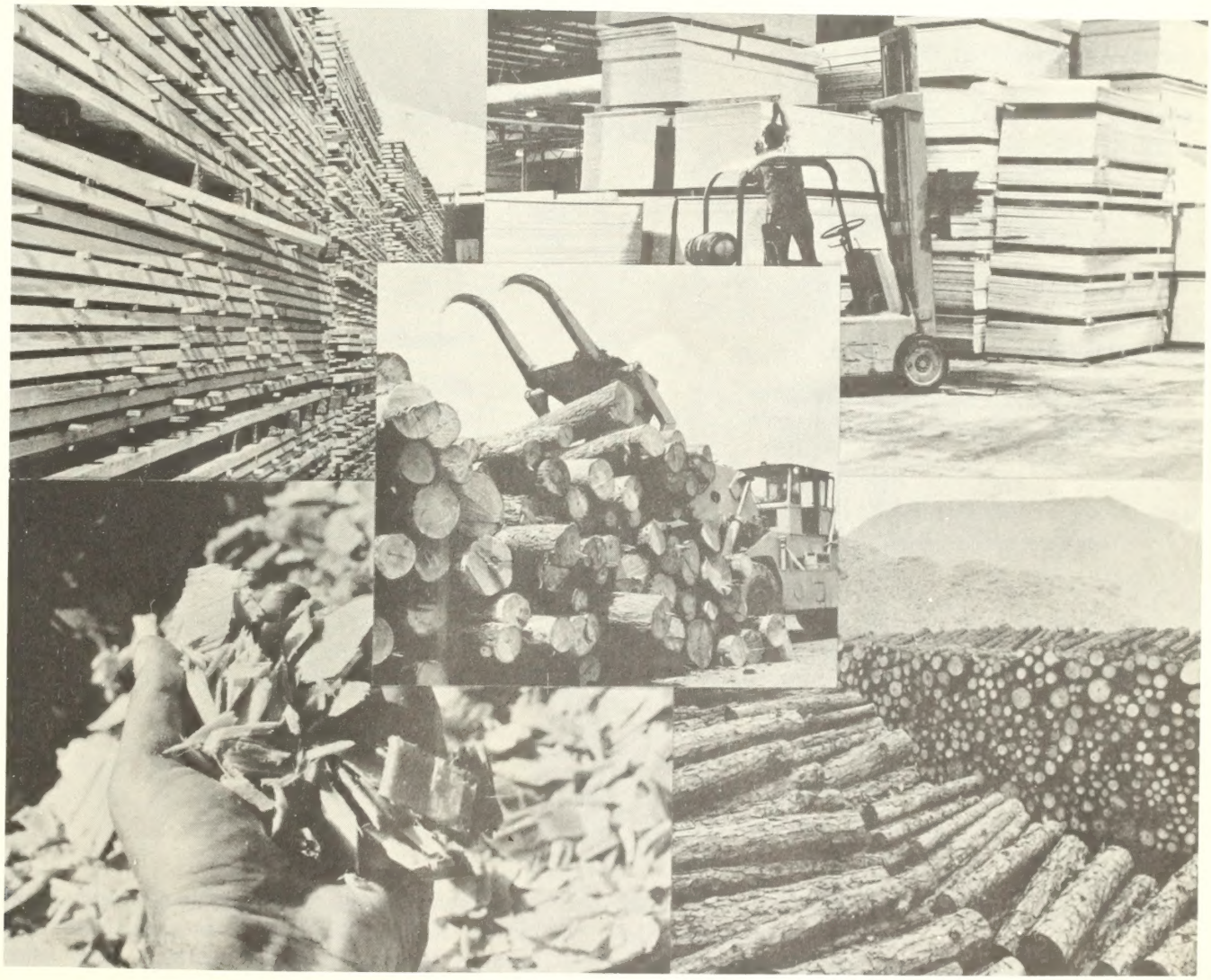
Research Paper
PNW-361

May 1986

ALABAMA'S Forest Products Industry: Performance and Contribution to the State's Economy, 1970 to 1980

Wilbur R. Maki, Con H Schallau, Bennett B. Foster, and Clair H. Redmond



Abbreviations

States

AL Alabama
AR Arkansas
FL Florida
GA Georgia
KY Kentucky
LA Louisiana
MS Mississippi
NC North Carolina
OK Oklahoma
SC South Carolina
TN Tennessee
TX Texas
VA Virginia

SO South
US United States

Industries

FPI Forest Products Industry
LWP Lumber and Wood Products
PAP Paper and Allied Products
WF Wood Furniture

Authors

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SB-361

Abstract

Maki, Wilbur R.; Schallau, Con H; Foster, Bennett B.; Redmond, Clair H. Alabama's forest products industry: performance and contribution to the State's economy, 1970 to 1980. Res. Pap. PNW-361. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

Employment and earnings in Alabama's forest products industry, like those of most Southern States, grew significantly between 1970 and 1980. The forest products industry accounted for a larger share of the State's economic base in 1980 than in 1970. Of the 13 Southern States, only 5 had more forest products industry employment than Alabama. Moreover, during this period, the State increased its share of the Nation's forest products industry employment and earnings. Paper and allied products had the highest productivity and experienced the largest increase in productivity between 1972 and 1977.

Keywords: Forest products industries, economics (forest products industries), Alabama.

Preface

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Alabama's forest products industry (paper and allied products; lumber and wood products, excluding mobile home manufacturing; and wood furniture manufacturing), like that of most Southern States, experienced significant growth during the 1970's. This resurgence resulted from the increasing size and amount of timber, investment in new plants and equipment, and a growing demand for Alabama's forest products.

This report briefly describes Alabama's forest products industry—its composition, location, evolution, and relation to economic activity elsewhere in the State, the South, and the Nation.

Estimates of employment and earnings shown in this report were derived from U.S. Department of Commerce data. All references to dollar amounts are in constant 1977 dollars.

This is one in a series of reports for each of the 13 Southern States. These reports are companions to an analysis of the changing roles of the forest products industries of the South and the Pacific Northwest.

Highlights

- Alabama's forest products industry gained in importance between 1970 and 1980. By 1980 it had surpassed fabricated and primary metals to become the State's third most important basic employer.

- The lumber and wood products industry is the largest segment of the State's forest products industry in terms of employment. The paper and allied products industry, however, accounted for more earnings and value added. Although it is the smallest component, wood furniture manufacturing was the fastest growing segment of Alabama's forest products industry during the 1970's in terms of employment and earnings. Lumber and wood products earnings grew slightly faster than those of paper and allied products.

- In 1980, average annual earnings in Alabama's forest products industry was about the same as for the Nation. Growth in Alabama's average earnings, however, exceeded growth for the South as well as for the Nation.

- In 1977, Alabama's forest products industry had the highest productivity (measured in terms of value added minus payroll, per worker hour) of any State in the South. It also experienced the greatest increase in productivity between 1972 and 1977.

- During the 1970's, Alabama increased its share of the Nation's employment and earnings in the forest products industry.

- In 1980, average earnings in Alabama's forest products industry were second highest among the 13 Southern States and about the same as the industry's U.S. average. Between 1970 and 1980, Alabama tied Georgia for third place in terms of growth in average annual earnings per worker.

- Earnings per worker in Alabama's paper and allied products industry were significantly greater than the earnings in the other segments of the forest products industry.

- In 1977, Alabama was one of the South's leading States in terms of value added by the forest products industry. It was second only to Texas for rate of change in value added between 1972 and 1977.

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The Forest Products Economy of Alabama

The State's Workforce

Alabama's estimated full- and part-time workforce in 1980 was comprised of an estimated 1.7 million employees and proprietors (see appendix tables for sources of employment and earnings data). Unlike most Sunbelt States, Alabama's workforce grew slightly slower between 1970 and 1980 than did the national average (21.4 percent versus 22.3 percent). But total earnings—wage and salary payments and proprietorial income—grew faster than the national average. Measured in constant 1977 dollars, the State's earnings increased by 30.6 percent as compared to 27.4 percent for the Nation. As can be seen in the following tabulation, manufacturing, services, State and local government, and retail trade were the State's four largest employer categories.

	Percent of total employment, 1980	
Employers	**Alabama**	**U.S.**
Major industries:		
Manufacturing (including forest products industry)	21.80	19.15
Services	15.40	18.22
State and local government	13.82	12.56
Retail trade	12.01	14.18
Nonfarm proprietors	6.32	6.58
Agriculture	6.16	4.39
Wholesale trade	4.33	4.97
Transportation, communication, and public utilities	4.31	4.84
Construction	4.25	4.08
Federal civilian	3.91	2.81
Federal military	3.20	2.30
Subtotal	95.51	94.08
All other industries	4.49	5.92
Total	100.00	100.00

Components of the State's Economic Base

Along with total employment there is another and perhaps more important way to judge an industry's contribution to Alabama's economy. For the State's economy to grow and develop, it must attract new dollars so residents can buy goods and services produced elsewhere. The industries that export products and services to other States and the world and bring in new dollars constitute the State's economic base. Generally speaking, most manufacturing employment is classified as economic base (or basic); service or residentiary employment (for example, barber shops, realty firms, schools, and local government) is primarily geared to producing for local needs.

Residentiary employment is supported by the economic base. Money flowing in provides income for wage earners and entrepreneurs to spend on locally purchased goods and services. In most cases, the economic growth of a region is dependent on the success of its economic base.

We used the excess employment and excess earnings techniques to identify the industries that comprise Alabama's economic base. This approach accepts the national distribution of employment and earnings among industries as a norm. Any industry with employment or earnings in excess of this norm is considered to be producing for export markets outside the State and is part of Alabama's economic base. The percentage of Alabama's excess employment and earnings served as an indicator of the State's dependency on a particular industry for generating new dollars from outside the State. (Table 2 shows how industry dependency indicators for Alabama were calculated.)

In 1980, ten industries accounted for 93.6 percent of the State's excess employment and 87.2 percent of its excess earnings (see tabulation below). Though these same industries accounted for only a slightly larger share (95.4 percent and 93.1 percent, respectively) in 1970, the change in shares of certain individual industries is noteworthy. Agriculture, and primary and fabricated metals, for example, were less important in 1980 than in 1970. Meanwhile, the forest products industry gained in importance between 1970 and 1980: In terms of basic employment, it replaced the primary and fabricated metals industry as the State's third most important basic industry. Agriculture continued to hold its position. Notice that although agriculture ranked as the State's second most important basic industry in terms of employment, it was a distant fifth in terms of basic earnings.

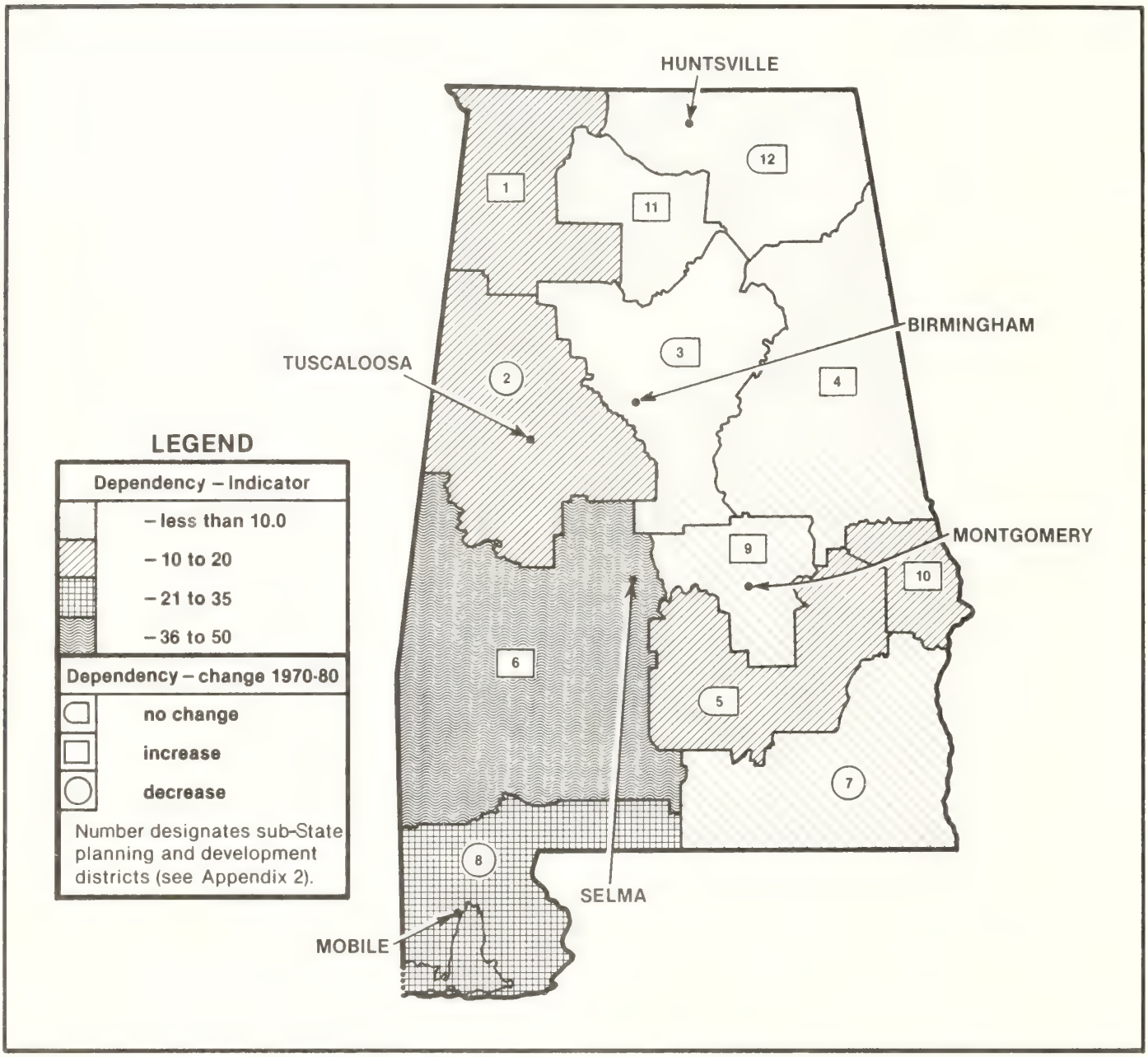
Economic base industries	Dependency indicator [1/]			
	1970		1980	
	EMP	EARN	EMP	EARN
	(Percent of economic base)			
Textile mill and apparel	27.7	20.8	30.5	20.1
Agriculture	24.7	7.7	16.1	6.5
Forest products industry [2/]	11.6	13.4	12.1	15.6
Primary metals	14.4	23.0	10.7	18.4
Federal civilian	8.1	19.8	9.5	16.2
Federal military	8.2	6.4	7.7	3.6
Construction	—	—	2.6	.1
Rubber and miscellaneous plastics	.5	1.6	1.7	4.0
Electrical, gas, and sanitation services	—	.4	1.5	2.7
Food and kindred products	.2	—	1.2	—
Subtotal	95.4	93.1	93.6	87.2
All other basic industries	4.6	6.9	6.4	2.8
Total	100.0	100.0	100.0	100.0

[1/]The indicators of economic dependency are expressed on an employment basis (EMP) and on an earning basis (EARN). For an explanation of the excess employment and other techniques for identifying basic industries, see Edgar M. Hoover. 1975. "An introduction to regional economics." 2d ed. New York, Alfred A. Knopf, Inc. 1975. 395 p.

[2/]The forest products industry is comprised of (1) lumber and wood products (SIC 24), except mobile homes (SIC 2451); and (2) wood furniture manufacturing (SIC 2511, 2512, 2517, 2521, 2541) and paper and allied products manufacturing (SIC 26).

Geographical Importance of the State's Forest Products Industry

The contribution of the forest products industry to Alabama's economic base—employment basis—varies considerably between sub-State districts (see appendix 2 for a listing of counties by district). Generally speaking, the forest products industry is more important in the western half of the State. Dependency on the forest products industry to produce exports remained the same or increased in most sub-State districts between 1970 and 1980.

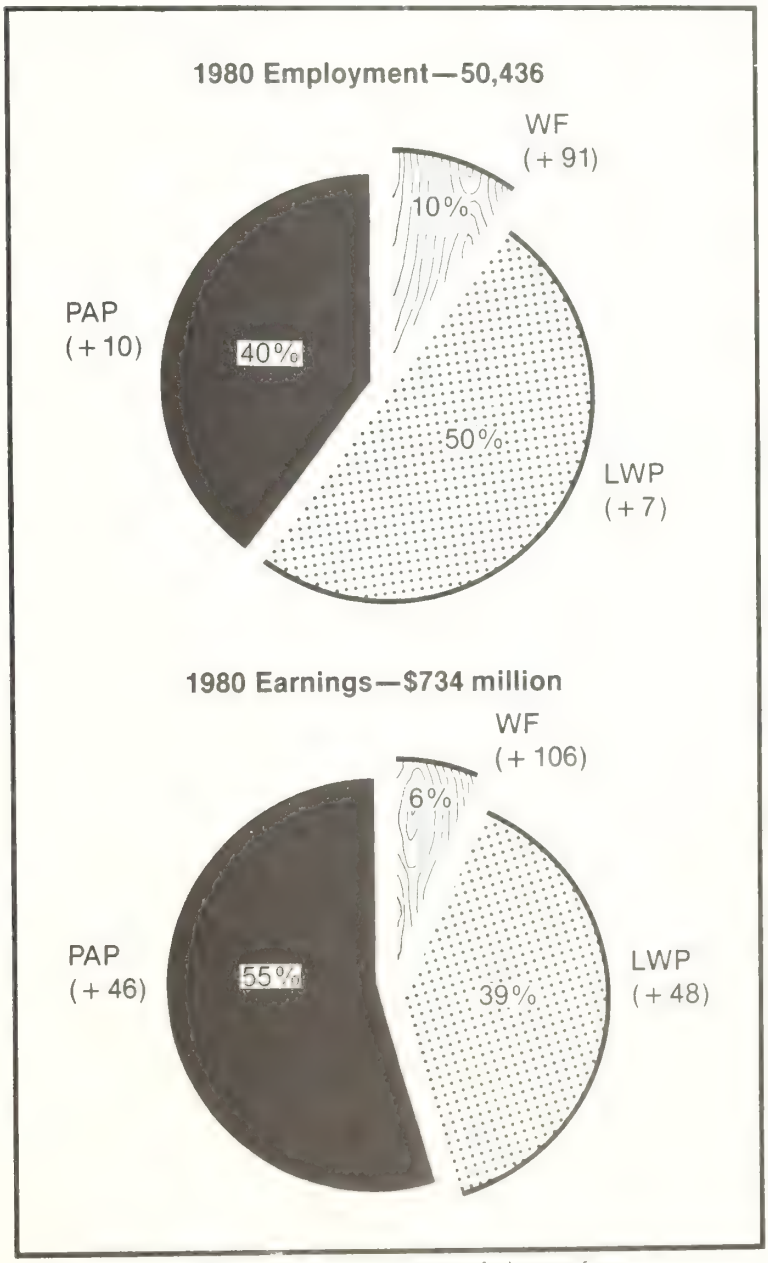


Source: Sub-State estimates for 1970 and 1980 were derived from unpublished county data series provided by the U.S. Department of Commerce, Regional Economic Information System, Washington, DC; and from the Department's *County Business Patterns*. The numbers in the squares and circles used to designate sub-State districts correspond to the geographical classification of counties as shown in appendix 2.

Composition of the State's Forest Products Industry

Alabama's forest products industry is comprised of paper and allied products, lumber and wood products (not including mobile homes), and wood furniture manufacturing. In 1980, lumber and wood products accounted for the largest share of approximately 50,000 workers employed by Alabama's forest products industry. Paper and allied products, however, had the largest share of 1980 earnings.

Employment in all three segments of Alabama's forest products industry increased between 1970 and 1980. In fact, wood furniture employment nearly doubled. Nevertheless, wood furniture manufacturing remains the smallest segment of the State's forest products industry. During this period, earnings more than doubled for the entire industry. Earnings in all three segments of the State's forest products industry increased much more rapidly than the average for all U.S. industries (27.4 percent). In fact, only two States in the South—Oklahoma and Texas—experienced more rapid growth in FPI earnings.

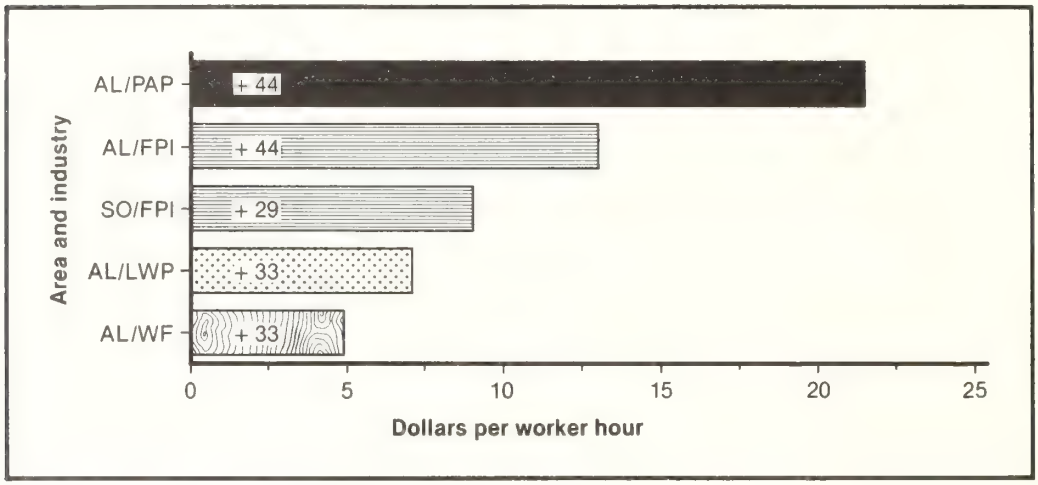


Numbers in parentheses show percentage of change from 1970 to 1980.

Capital Productivity

Increases in productivity are necessary for an industry to remain competitive in the marketplace. Capital productivity of an industry is measured in terms of value added less payrolls per worker hour—VAMP (see table 3 for an explanation of how capital productivity was calculated for Alabama's forest products industry). This measure of productivity adjusts for wide differences in payroll among industries and represents the return to capital investment and entrepreneurship.

Not surprisingly, paper and allied products had the highest productivity in Alabama's forest products industry. This segment is more capital intensive and in the past has attracted considerable investment in new facilities and equipment. Furthermore, during the mid-1970's, this segment exhibited a larger gain in productivity than did either wood furniture or lumber and wood products.

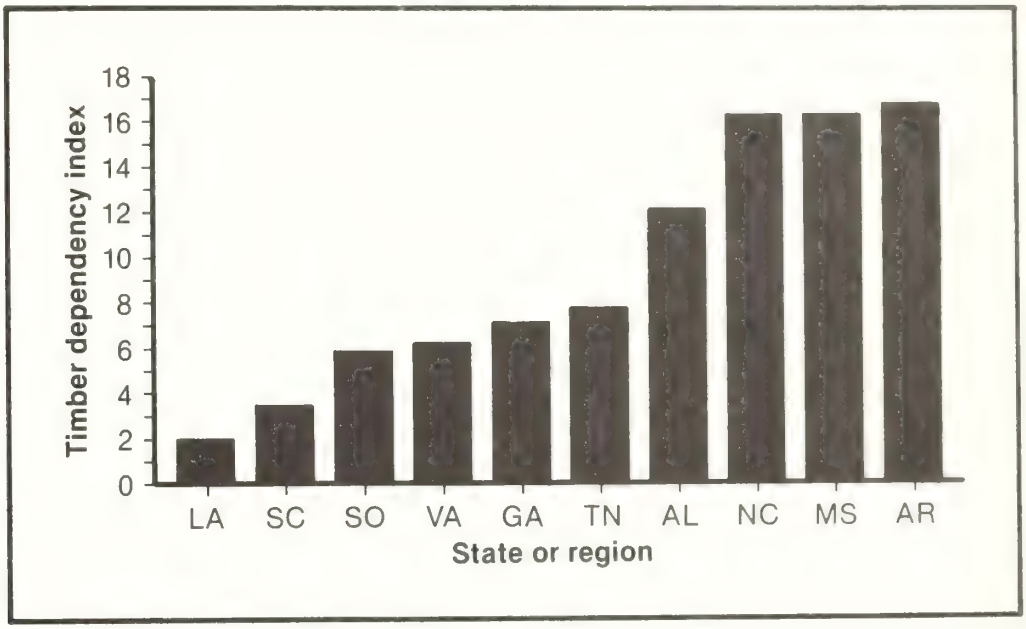


Numbers in bars show percentage of change from 1972 to 1977.

The Forest Products Industry in the South

Importance of the Industry Across the South

The dependency indicators suggest that in 1980 all but four States in the South manufactured forest products in excess of statewide needs. Florida, Oklahoma, Kentucky, and Texas were not self-sufficient with respect to forest products. Consequently, on net balance, their respective forest products industries did not generate new dollars from outside. In Alabama, the forest products industry accounts for approximately 1 out of 8 employees in the basic sector. In three other Southern States—Arkansas, Mississippi and North Carolina—it accounts for approximately 1 out of 6 basic employees.



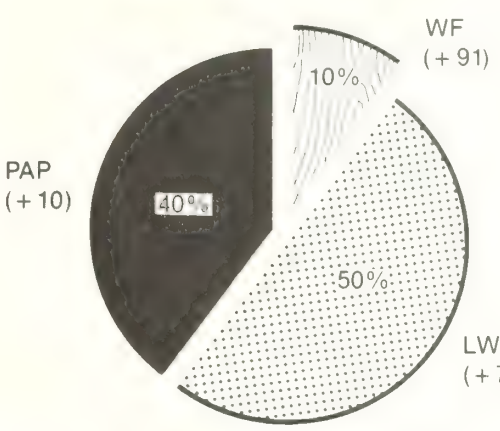
Industry Composition

Lumber and wood products accounted for a larger share of Alabama's 1980 forest products industry employment than it did for either the South or the Nation. Paper and allied products manufacturing was more important in Alabama than in the South in terms of total employment. Employment growth, however, was faster in the South. Although paper and allied products was less important in Alabama than for the Nation, employment growth in Alabama was much greater.

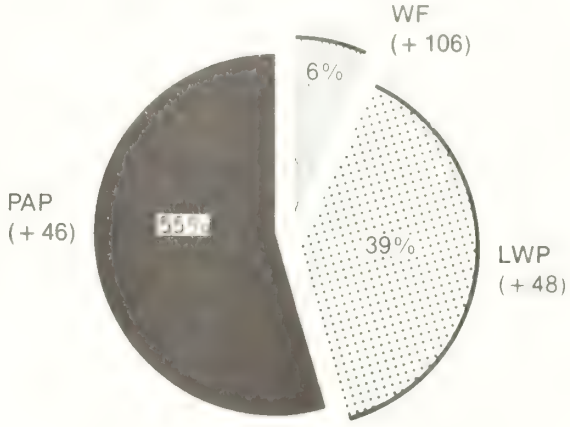
In terms of total earnings, the composition of Alabama's forest products industry resembled the Nation. But growth in earnings in all of Alabama's forest products industries exceeded the average for their counterparts in the South and the Nation.

ALABAMA

1980 Employment—50,436

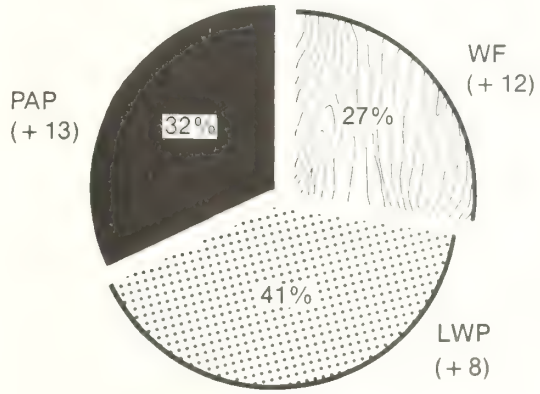


1980 Earnings—$734 million

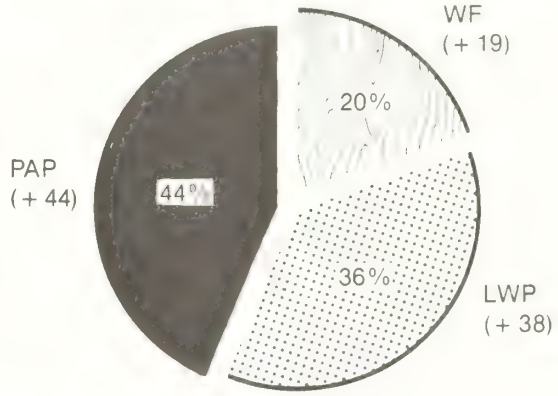


THE SOUTH

1980 Employment—620,567

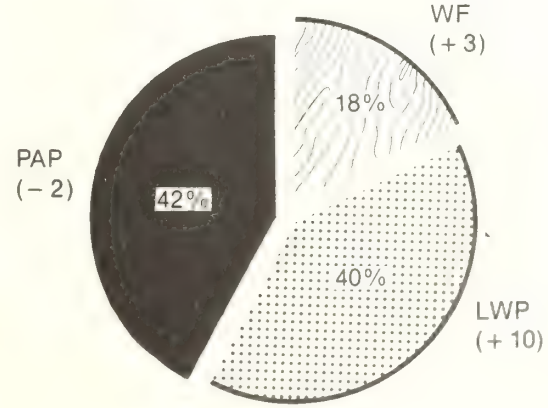


1980 Earnings—$7.96 billion

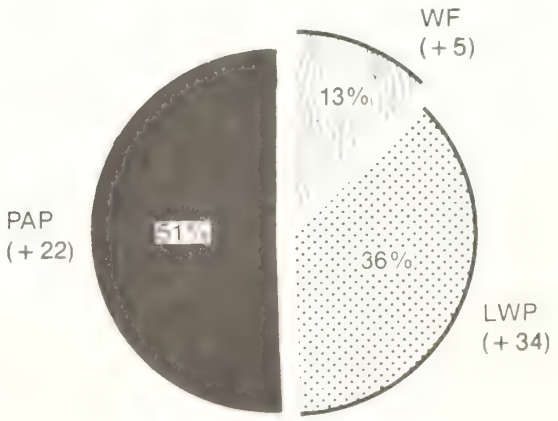


UNITED STATES

1980 Employment—1,634,000



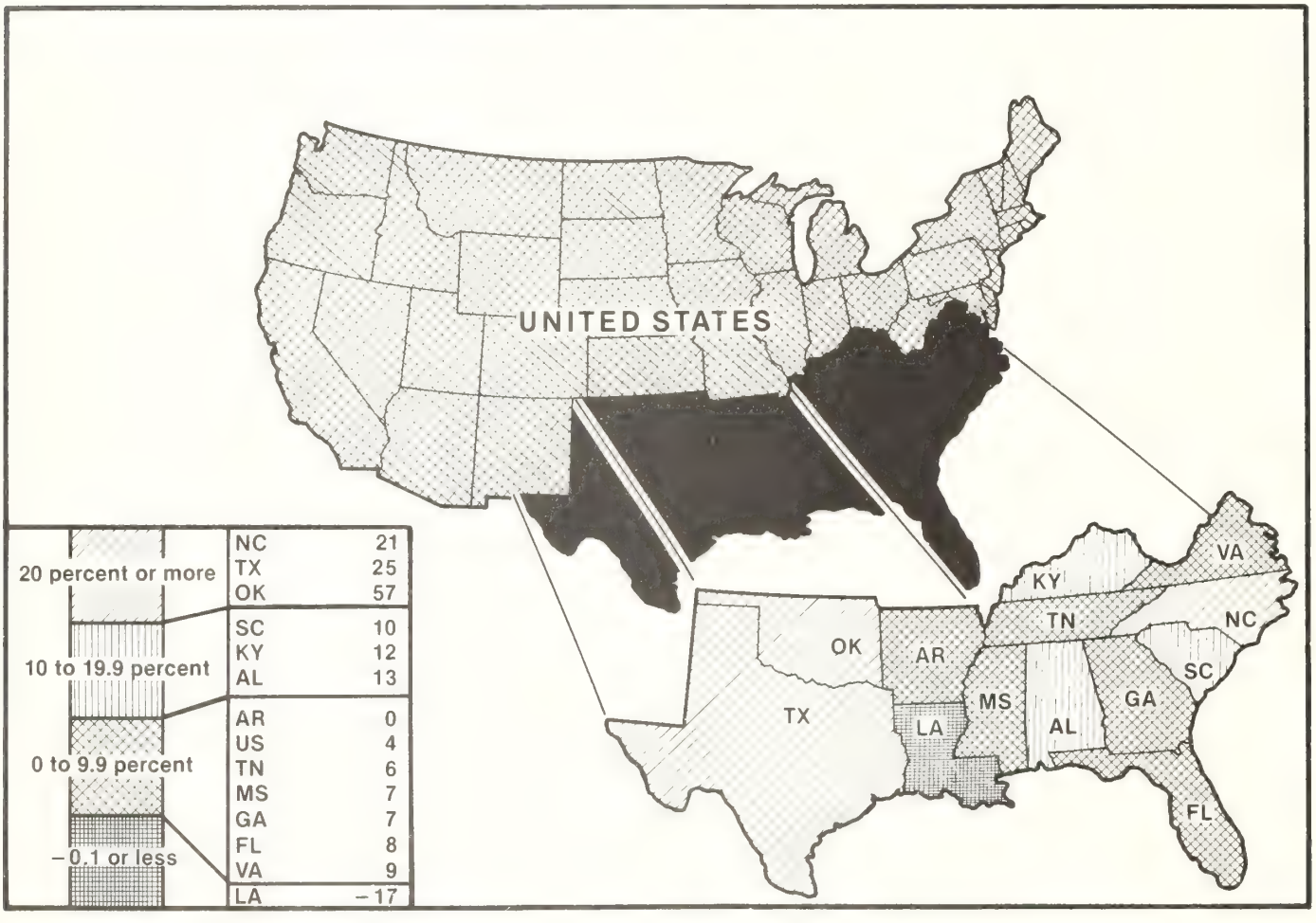
1980 Earnings—$23.65 billion



Numbers in parentheses show percentage of change from 1970 to 1980.

Growth of Employment

With the exception of Arkansas and Louisiana, forest products industry employment in each of the Southern States grew faster than did the U.S. counterpart. Employment in two States—Oklahoma and Texas—grew faster than the all-industry average of 22.3 percent. Employment growth in Alabama's forest products industry was over three times the national rate and ranked fourth among the 13 Southern States.

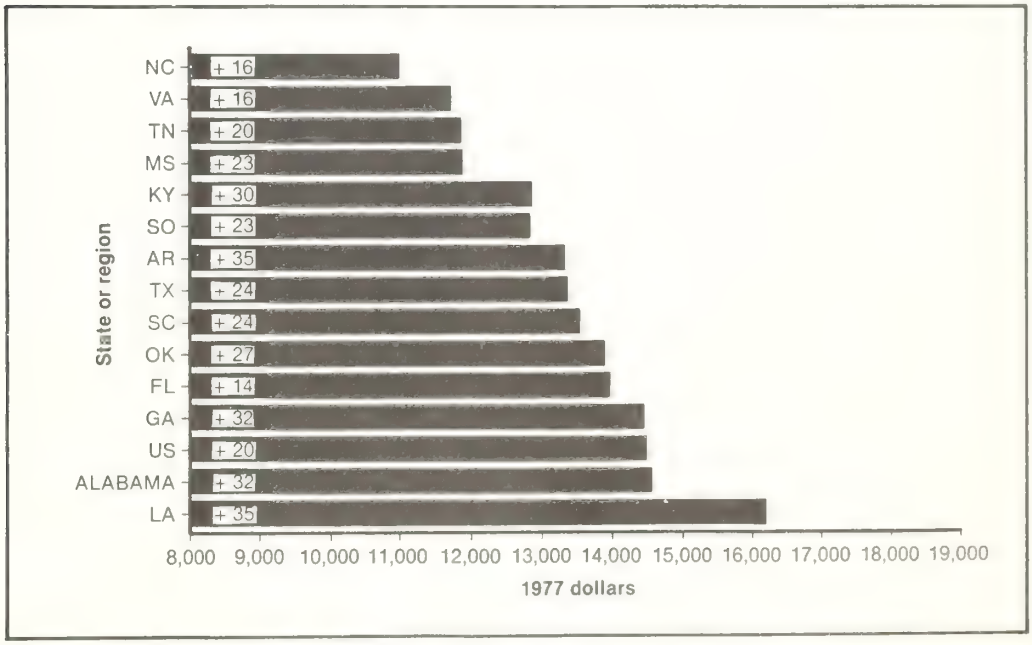


Average Annual Earnings

Average annual earnings per worker in the forest products industry differed significantly by State in 1980: Approximately $5,000 separated the State with the highest—Louisiana—from the State with the lowest—North Carolina. Pulp and allied products manufacturing, which has traditionally paid higher wages than have other forest products industries, dominated Louisiana's forest products industry. Wood furniture, which has paid lower average wages, dominated North Carolina's industry.

Average annual earnings per worker in Alabama's forest products industry were second highest in the South. Furthermore, Alabama tied Georgia for third place in terms of growth in average annual earnings per worker. The forest products industry average annual earnings in Alabama were nearly the same as the industry's U.S. average.

Generally speaking, paper and allied products dominated the forest products industry in the States with the hightest average annual earnings. This relationship reflects higher job skills and unions in the paper industry. Wages, by and large, were the lowest in those States where the labor-intensive wood furniture industry was more important.



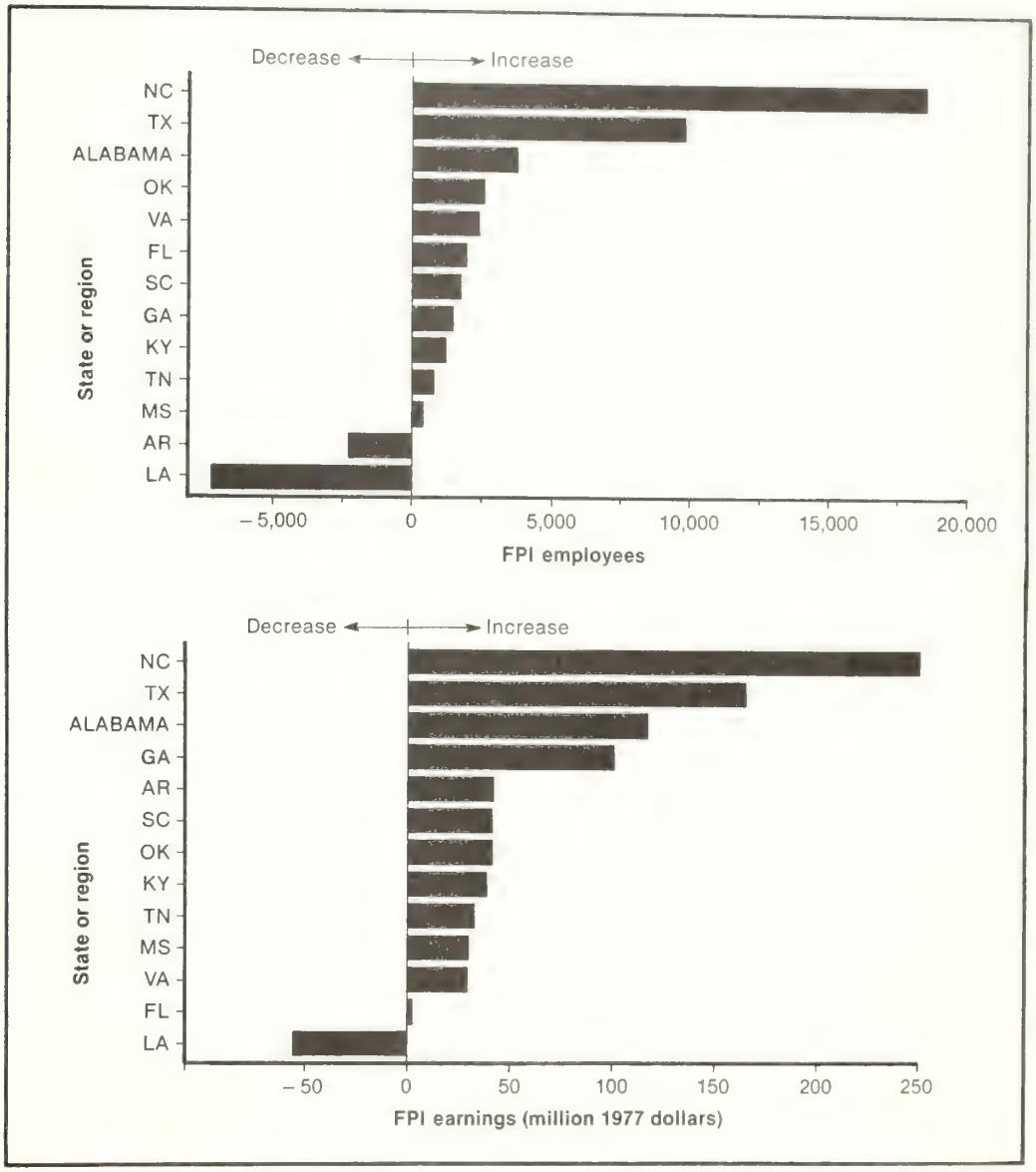
Numbers in bars show percentage of change from 1970 to 1980.

Shift in Employment and Earnings

The regional shift shows how much more or less employment and earnings a State would have had in the forest products industry in 1980 had it grown at the national rate. For example, Alabama had approximately 3,700 more employees in 1980 than it would have had if its forest products industry had grown at the national rate.

Between 1970 and 1980, in both employment and earnings, the forest products industry increased in every Southern State except Louisiana and Arkansas. Moreover, all but these two States increased their share of the Nation's forest products industry employment, and all States except Louisiana increased their share of earnings.

Increased shares of employment and earnings reflect the comparative advantage the South's forest products industry enjoyed over this industry in the rest of the Nation. Several factors (for example, relatively lower labor costs, lower raw materials costs, and closer proximity to markets) might account for a region's comparative advantage, although adverse trends with respect to one factor need not reduce a region's advantage. In the case of the South, for instance, increasing labor costs need not adversely affect its comparative advantage if increased capital or labor productivity offsets higher labor costs.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SC
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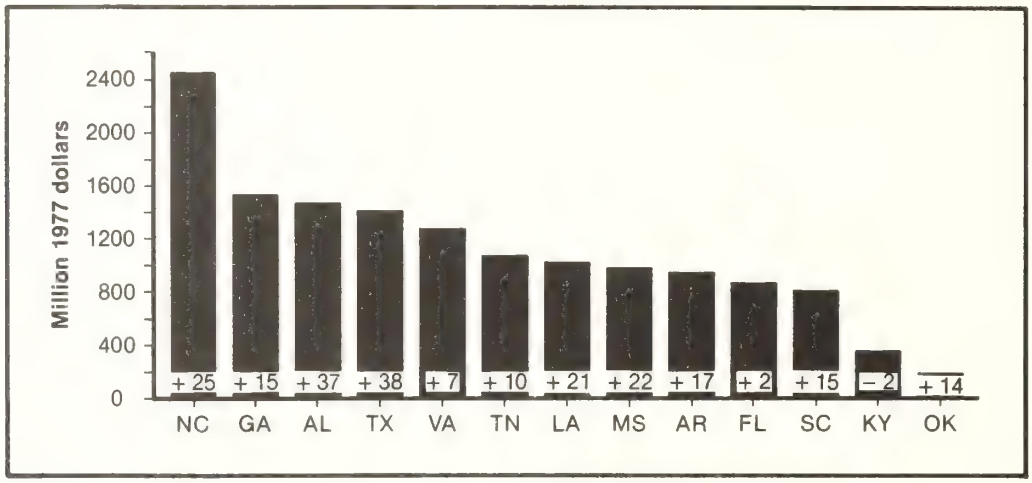
KY
TN
MS
VA
FL
LA
State or region
– 50
0
50
100
150
200
250
FPI earnings (million 1977 dollars)

Value Added by the Forest Products Industry

In 1977, the forest products industry of North Carolina produced more value added than any other State in the South. Georgia was second among the 13 Southern States, followed by Alabama. Alabama was not only one of the leading States in terms of total value added, it was second only to Texas in terms of the change in value added between 1972 and 1977. One State, Kentucky, produced less value added in 1977 than in 1972.

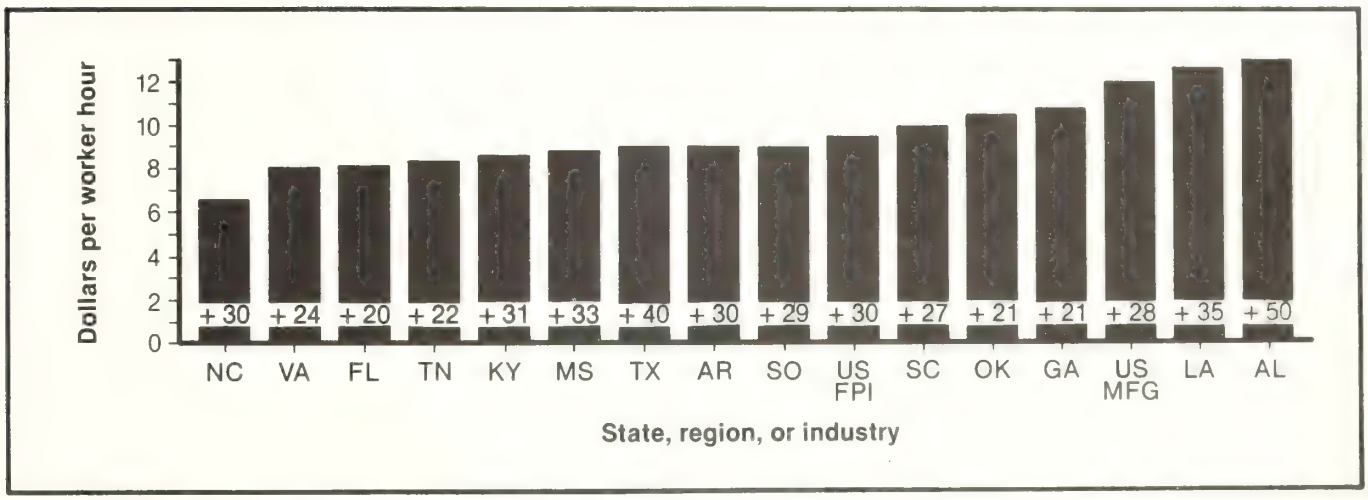


Numbers in bars show percentage of change from 1972 to 1977.

Capital Productivity

Paper and allied products, which is more capital-intensive and, therefore, more susceptible to technological change than other segments of the forest products industry, exhibited the highest productivity within the forest products industry. Wood furniture, on the other hand, is the most labor-intensive of the three segments. North Carolina, for example, produced more value added than any other State in the South, but the productivity of its forest products industry in 1977 was the lowest. This reflects the dominant role of the labor-intensive wood furniture industry in North Carolina.

Increases in productivity exceeded increases in payroll per worker between 1972 and 1977 for all the Southern States. This relationship is in part responsible for the South's comparative advantage in the forest products industry. Alabama led the South both in productivity in 1977 and in change between 1972 and 1977. Furthermore, the productivity of Alabama's forest products industry exceeded that for the United States and the average for all manufacturing.



Numbers in bars show percentage of change from 1972 to 1977.

Acknowledgment

Many helpful suggestions of several reviewers were incorporated in this research paper. This project was partially funded by USDA Forest Service, Resource Program and Assessment Staff, State and Private Forestry, Area Planning and Development, State Planning for Forest Resources.

Appendix 1
Tables

Table 1—Total labor and proprietorial employment and income, by industry, Alabama, 1980[1/]

Industry number	Industry	Employees	Total income
		Number	*Thousand 1977 dollars[2/]*
Wage and salary			
1	Agriculture	24,133	401,896
2	Agricultural services, forestry, and fisheries	6,545	64,876
3	Coal mining	12,539	322,909
4	Oil and gas extraction	1,181	26,073
5	Metal mining	101	2,127
6	Nonmetallic minerals	2,350	38,170
7	Construction	71,107	976,374
8	Food and kindred products	28,413	305,278
9	Tobacco	793	7,278
10	Textile mill production	42,916	423,243
11	Apparel and other textiles	54,134	371,124
12	Paper and allied products	20,020	400,549
13	Printing and publishing	10,076	116,762
14	Chemical and allied products	15,574	288,436
15	Petroleum refining	1,553	31,728
16	Rubber and miscellaneous plastics	14,647	245,590
17	Leather and leather products	198	1,979
18	Lumber and wood products, except mobile homes	25,408	286,172
19	Mobile homes	2,814	31,694
20	Wood furniture	5,008	47,007
21	Other furniture and fixtures	2,955	27,737
22	Stone, clay, and glass products	9,907	141,939
23	Primary metals	39,304	829,326
24	Fabricated metals	25,398	344,508
25	Machinery, excluding electrical	15,844	215,860
26	Electrical machinery	18,486	227,491
27	Transportation equipment, except motor vehicles	15,993	278,508
28	Motor vehicles	7,256	128,039
29	Ordnance	[3/]	[3/]
30	Instruments and related equipment	3,154	35,243
31	Miscellaneous manufacturing	4,740	49,896
32	Railroad transportation	7,627	152,387
33	Trucking and warehousing	19,697	308,505
34	Local transit	1,503	15,114

See footnotes at end of table.

Table 1—Total labor and proprietorial employment and income, by industry, Alabama, 1980 [1/] (continued)

Industry number	Industry	Employees	Total income
		Number	*Thousand 1977 dollars [2/]*
Wage and salary			
35	Air transportation	1,173	18,869
36	Pipeline transportation	92	1,692
37	Transportation services	944	15,162
38	Water transportation	3,824	59,082
39	Communications	21,378	394,033
40	Electrical, gas, and sanitation services	15,776	292,796
41	Wholesale trade	72,440	1,042,624
42	Retail trade	200,874	1,534,919
43	Banking	20,056	208,947
44	Other credit agencies	9,736	133,533
45	Insurance	20,081	314,285
46	Real estate and combinations	9,253	112,655
47	Hotel and other lodging	10,243	61,666
48	Personal, miscellaneous business, and repair services	44,587	430,003
49	Auto repair service	7,788	98,400
50	Amusement	5,624	34,318
51	Motion pictures	1,255	5,972
52	Private households	59,469	135,595
53	Medical and other health	66,797	882,469
54	Private eductation	12,505	92,271
55	Nonprofit organizations	35,227	201,895
56	Miscellaneous services	14,086	310,769
57	Federal civilian	65,445	1,067,464
58	Federal military	53,485	341,092
59	State and local government	231,119	2,009,163
Proprietorial			
60	Farm proprietors	72,341	329,199
61	Nonfarm proprietors	105,683	1,059,397
	Total	1,672,655	18,332,088

[1/] Source of data for this table for Alabama, other States of the South, and the United States: unpublished data, U.S. Department of Commerce, Regional Economics Measurements Division, Regional Economic Information System (REIS), Washington, DC, 1982. Unpublished data used by the U.S. Department of Commerce in preparing their *County Business Patterns* (CBP) series on employment and payroll were used to differentiate wood-related from nonwood-related employment and earnings. For example, CBP data were used to separate mobile homes (no. 19, above) from the lumber and wood products (no. 18) industry. Wood furniture (no. 20) was similarly separated from other furniture and fixtures (no. 21).

[2/] The Personal Consumption Expenditures (PCE) deflator, 1977 = 100, was used to deflate actual dollars.

[3/] Included with fabricated metals and other related industries.

Table 2—Calculation of 1980 dependency indexes for Alabama [1/]

(In percent)

Industry	Employment		Alabama excess employment [2/]	Dependency index [3/]
	Alabama	United States		
Agriculture	1.75	1.46	0.28	1.85
Agricultural services, forestry, and fisheries	.47	.62	—	—
Farm proprietors	5.23	3.03	2.20	14.29
Coal mining	.91	.27	.63	4.10
Oil and gas extraction	.09	.60	—	—
Metal mining	.01	.11	—	—
Nonmetallic minerals	.17	.14	.03	.22
Construction	5.14	4.74	.40	2.60
Food and kindred products	2.06	1.87	.19	1.21
Tobacco	.06	.07	—	—
Textile mill production	3.11	.93	2.17	14.10
Apparel and other textiles	3.92	1.39	2.53	16.40
Paper and allied products	1.45	.76	.69	4.49
Printing and publishing	.73	1.37	—	—
Chemical and allied products	1.13	1.22	—	—
Petroleum refining	.11	.22	—	—
Rubber and miscellaneous plastics	1.06	.80	.26	1.71
Leather and leather products	.01	.26	—	—
Lumber and wood products, except mobile homes	1.84	.71	1.13	7.32
Mobile homes	.20	.05	.15	.99
Wood furniture	.36	.32	.04	.26
Other furniture and fixtures	.21	.19	.03	.17
Stone, clay, and glass products	.72	.73	—	—
Primary metals	2.84	1.26	1.58	10.25
Fabricated metals	1.84	1.77	.06	.41
Machinery, excluding electrical	1.15	2.73	—	—
Electrical machinery	1.34	2.31	—	—
Transportation equipment, except motor vehicles	1.16	1.21	—	—
Motor vehicles	.53	.87	—	—
Ordnance			0	0
Instruments and related equipment	.23	.77	—	—
Miscellaneous manufacturing	.34	.47	—	—
Railroad transportation	.55	.58	—	—
Trucking and warehousing	1.43	1.40	.02	.16
Local transit	.11	.29	—	—
Air transportation	.08	.50	—	—
Pipeline transportation	.01	.02	—	—
Transportation services	.07	.22	—	—
Water transportation	.28	.23	.05	.30
Communications	1.55	1.48	.07	.42
Electrical, gas, and sanitation services	1.14	.90	.24	1.54
Wholesale trade	5.24	5.79	—	—
Retail trade	14.53	16.50	—	—
Banking	1.45	1.72	—	—

See footnotes at end of table.

Table 2—Calculation of 1980 dependency indexes for Alabama [1/] (continued)
(In percent)

Industry	Employment		Alabama excess employment [2/]	Dependency index [3/]
	Alabama	United States		
Other credit agencies	.70	0.99	—	—
Insurance	1.45	1.89	—	—
Real estate and combinations	.67	1.16	—	—
Hotel and other lodging	.74	1.20	—	—
Personal, miscellaneous business, and repair services	3.23	4.69	—	—
Auto repair service	.56	.63	—	—
Amusement	.41	.84	—	—
Motion pictures	.09	.24	—	—
Medical and other health	4.83	5.71	—	—
Private education	.90	1.47	—	—
Nonprofit organizations	2.55	3.01	—	—
Miscellaneous services	1.02	1.63	—	—
Federal civilian	4.74	3.27	1.47	9.50
Federal military	3.87	2.68	1.19	7.71
Nonfarm proprietors	7.65	7.66	—	—
Total [4/]	100.0	100.00	15.43	100.00

[1/]For an explanation of the excess employment and other techniques for identifying basic industries, see Edgar M. Hoover. 1975. "An Introduction to Regional Economics." 2d ed. New York, Alfred A. Knopf, Inc. 395 p.

[2/]U.S. employment minus Alabama employment. Figures may not be exactly equal to Alabama minus U.S. because of rounding. Dashes signify no excess employment.

[3/]Individual industry excess employment expressed as a percentage of Alabama's total excess employment (sum of column 4).

[4/]Sum of parts may not equal totals because of rounding.

Table 3—Value added, hours worked, payroll, and capital productivity, [1/] Alabama forest products industry, 1977 [2/]

Industry	Value added	Payroll	Hours worked	Productivity	Productivity change, 1972-77
	- - *$Million* - -		*Million*	*$VAMP per hour*	*Percent*
Lumber and wood products	429.0	183.0	34.9	7.05	33.41
Wood furniture	67.1	32.8	7.0	4.90	33.30
Paper and allied products	966.3	299.2	31.0	21.52	43.56

[1/]Productivity equals value added (VAMP) minus payroll divided by hours worked. For a discussion of VAMP, see W. Charles Sawyer and Joseph A. Ziegler. 1980. "The use of VAMP shift as a predictive model." Unpublished paper presented at the annual meeting of the Western Regional Science Association, Monterey, California.

[2/]Source: U.S. Bureau of the Census, Census of Manufacturing, for 1972 and 1977, Alabama and the United States, available in 1976 and 1980, respectively. In the few instances where data were not available for some subindustry sectors, the distribution of the number of establishments was used to estimate nondisclosures.

Appendix 2
Alabama Counties by Sub-State Planning and Development Districts

District code	Counties
1	Colbert, Franklin, Lauderdale, Marion, Winston
2	Bibb, Fayette, Greene, Hale, Lamar, Pickens, Tuscaloosa
3	Blount, Chilton, Jefferson, St. Clair, Shelby, Walker
4	Calhoun, Chambers, Cherokee, Clay, Cleburne, Coosa, Etowah, Randolph, Talladega, Tallapoosa
5	Bullock, Butler, Crenshaw, Lowndes, Macon, Pike
6	Choctaw, Clarke, Conecuh, Dallas, Marengo, Monroe, Perry, Sumter, Washington, Wilcox
7	Barbour, Coffee, Covington, Dale, Geneva, Henry, Houston
8	Baldwin, Escambia, Mobile
9	Autauga, Elmore, Montgomery
10	Lee, Russell
11	Cullman, Lawrence, Morgan
12	De Kalb, Jackson, Limestone, Madison, Marshall

Maki, Wilbur R.; Schallau, Con H; Foster, Bennett B.; Redmond, Clair H. Alabama's forest products industry: performance and contribution to the state's economy, 1970 to 1980. Res. Pap. PNW-361. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

Employment and earnings in Alabama's forest products industry, like those of most Southern States, grew significantly between 1970 and 1980. The forest products industry accounted for a larger share of the State's economic base in 1980 than in 1970. Of the 13 Southern States, only 5 had more forest products industry employment than Alabama. Moreover, during this period, the State increased its share of the Nation's forest products industry employment and earnings. Paper and allied products had the highest productivity and experienced the largest increase in productivity between 1972 and 1977.

Keywords: Forest products industries, economics (forest products industries), Alabama.

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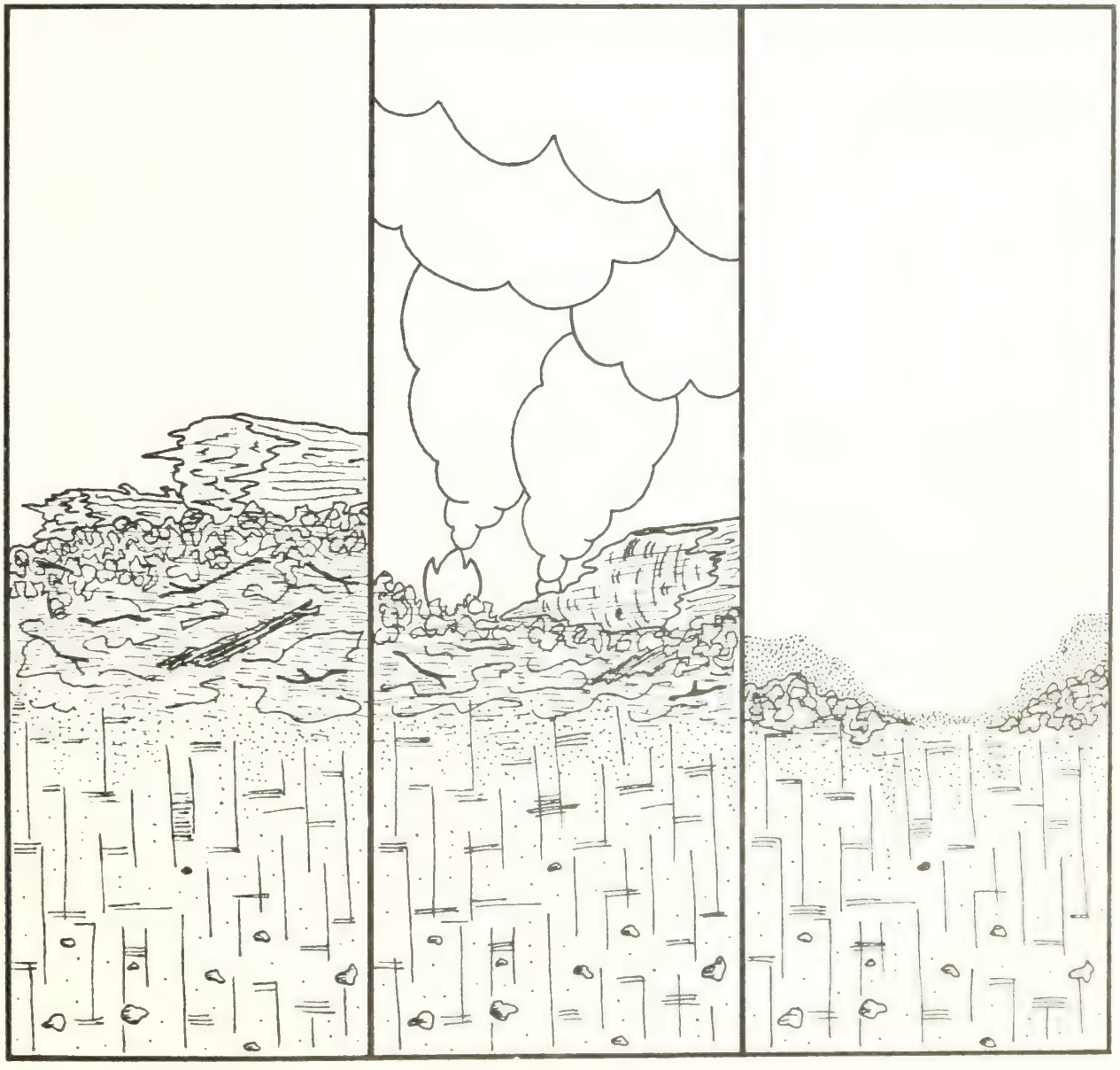
Predicting Duff Consumption From Prescribed Burns on Conifer Clearcuts in Western Oregon and Western Washington

Susan N. Little, Roger D. Ottmar, and Janet L. Ohmann



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Abstract

Little, Susan N.; Ottmar, Roger D.; Ohmann, Janet L. Predicting duff consumption from prescribed burns on conifer clearcuts in western Oregon and western Washington. Res. Pap. PNW-362. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 29 p.

Duff consumption by fire was studied on 15 cable-yarded clearcut units in western Oregon and western Washington. Equations are presented that predict duff consumption (in depth reduction and weight loss) from loading, consumption, and moisture of large fuels, and days since significant precipitation. When more than 25 days elapsed since 1.3 cm rainfall, the effect of large fuel loading on duff consumption diminished. Duff consumption was dependent on the diameter reduction of large fuels when there had been no rain for at least 25 days. The results indicated that duff consumption can be reduced by removing large fuel before the burn, scheduling the burn under moist conditions, or both. Methods are demonstrated to prescribe the proper level of fuel removal and moisture regime at time of burn to achieve a given level of duff consumption.

Keywords: Duff consumption, duff reduction, fire effects, prescribed burning, duff moisture, mineral soils, clearcuts.

Summary

Duff consumption by broadcast fire was studied on 15 cable-yarded clearcuts in western Oregon and western Washington. Units were divided into treatment blocks where either the amount of large fuels (greater than 7.62 cm diameter outside bark (d.o.b.)) or the moisture content of large fuels varied within the unit. Duff consumption was predicted from large fuel loading, consumption, moisture content, and days since rainfall. Prediction of duff consumption was enhanced by dividing the data into two populations: burns conducted less than 25 days since rainfall and burns conducted more than 25 days since rainfall. The duff consumption from burns in the first population depended on consumption of large fuels. Duff consumption depended on the diameter reduction of large fuels on burns that had not received rainfall for more than 25 days.

Mineral soil exposed during burns was predicted from preburn duff depth and days since rainfall.

The results suggested that savings in duff consumption can be achieved by removing large fuel before the burn, by scheduling the burn under moist conditions, or both. Methods are demonstrated for prescribing the proper level of fuel removal and moisture regime at the time of burning to achieve a given level of duff consumption.

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Introduction

In this paper, we quantify (1) the effects of wood removal on the consumption of duff during prescribed burning and (2) the relationship between fuel loading and moisture content with regard to duff consumption. Forest managers in the Pacific Northwest prescribe fire as a treatment after timber harvest to reduce wildfire hazard, control competing vegetation, and facilitate planting. Even though fire has been proven to be a cost-effective tool for meeting these objectives, it has some undesirable effects. Burning the forest floor contributes to emissions during prescribed burns, reduces nutrient pools, and increases erosion hazard through exposure of mineral soil. The severity of these impacts depends on the duration and intensity of the fire, which in turn depend on the amount and moisture content of woody fuels. New markets have developed and are increasing for alternative wood products, including new fiber products and fuel wood for industrial and home consumption. This has led to removal of large amounts of wood from harvest sites—wood that would otherwise burn during site treatment. Hence, removing large amounts of wood from clearcuts will reduce duff consumption and allow the manager to meet site treatment objectives. The results of this study should enable managers to evaluate the effectiveness of increased wood utilization in reducing the negative impacts of prescribed burns.

The mantle of decaying organic matter above the forest soil (litter, fermentation, and humus layers, hereafter referred to as "duff") provides benefits to site productivity and soil stability. It serves as a protective layer by insulating the soil from temperature extremes, by retaining moisture, and by protecting the soil from erosion. Duff acts as a nutrient sink; the duff stores nutrients accumulated by the stand over the years and releases these nutrients to the forest as decay progresses. In some ecosystems, most of the nitrogen used in support of timber growth comes from this mantle.

Duff is disturbed to various degrees by timber harvesting; how much disturbance depends on the yarding system used and the slope of the harvest unit. Prescribed fire, used to treat the site for fire hazard reduction, brush control, and generation of planting sites, has the greatest potential to disturb duff of any management activity. Burning removes duff and exposes the mineral soil to erosion and temperature extremes. Nitrogen, one of the nutrients in short supply in the Pacific Northwest, is volatilized during the burn. Furthermore, duff consumed during a burn can contribute to over half of the particulate emissions from the burn (Sandberg 1984). On sites where the duff is exceptionally thick, managers may want to remove a portion of this mantle to ensure that seedlings are planted in mineral soil and that water can penetrate to their roots. Whether the objective is to retain or remove the duff, equations that predict duff consumption from fuel loading and moisture content are needed to set accurate burning prescriptions and to evaluate the utility of removing woody fuel before burning. The purpose of this study was to develop equations that will be applicable to conifer clearcuts in western Oregon and western Washington.

Review

The Role of Moisture in Duff Consumption

The amount of duff consumed during a prescribed burn depends on the moisture profile of the duff and on the amount and duration of heat from the burning woody fuel. Duff will burn independently of heat provided by burning woody fuel at a moisture content of 30 percent (Shearer 1975). The amount of heat needed to draw off moisture to that level depends, of course, on how wet the duff is before ignition. If a dry layer exists on the surface, it may reduce heat penetration in the duff profile, and duff consumption will be dependent on fire duration.

Predicting duff moisture.—The duff moisture profile depends on a number of physical properties, such as hydraulic conductivity and porosity (Fosberg 1977), topographic position (Hillhouse and Potts 1982), and weather. For sites where the physical characteristics of the duff are relatively uniform (for example, pine stands created by severe wild fire), the duff moisture profile will be relatively uniform and predictable from weather data. The Canadian Duff Moisture Index (DMC), developed for jack and red pine (*Pinus banksiana* Lamb. and *P. resinosa* Ait.), predicts duff moisture based on precipitation, temperature, and relative humidity (Van Wagner 1970). The DMC is based on empirical evidence that pine duff dries exponentially. Van Wagner (1982) established that the rate of drying is independent of initial moisture content. Although DMC has been a successful predictor for moisture content of pine duff, it has not been proven successful for west-side Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sargent) duff, which is much more variable across a unit.

In a laboratory experiment on five conifer duff types from California, Stocks (1970) found that 1.3 cm of rainfall wet the litter layer as well as did 5.1 cm of rainfall, and that 1.3 cm of rainfall was sufficient to raise the moisture content of a dry litter layer to 120 percent. The wetting of the litter to that moisture content should preclude ignition of duff in the absence of heat from woody fuel (Sandberg 1980).

Cooper [1/] studied drying of individual duff types and depths. Duff beds consisting of either litter and litter-derived humus (bulk density of 0.12 g/cm^3) or rotten material (bulk density of 0.18 g/cm^3) were constructed to depths of 5.1 cm and 10.2 cm. These beds were saturated and then allowed to dry in the laboratory. Preliminary results suggested that, under constant temperature and humidity, it takes 7 days (for duff derived from needles) to 16 days (for duff derived from rotten woody material) for the top 2.5 cm of duff to dry to 30-percent moisture content. Using an adjustment developed by Fosberg and others (1970) to extrapolate laboratory results to field conditions (where the diurnal flux of temperature and humidity prolong the drying period), Cooper concluded that 25 days are needed to dry the top 2.5 cm of duff to a moisture content of 30 percent. At this moisture content, duff should burn independently of woody fuel loading.

[1/]Unpublished Report, 1985, "The second report on progress made toward predicting the occurrence of a dry lower duff layer," by Kathy L. Cooper, U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, 4043 Roosevelt Way, NE, Seattle, WA 98105.

Predicting duff consumption from moisture variables.—Published equations for predicting duff consumption from moisture variables are listed in table 1. Van Wagner (1972) relates weight of duff consumed during underburning to fire duration and the inverse of duff moisture. Chrosciewicz (1978a, 1978b) and Blackhall and AuClair (1982) also predict duff consumption from DMC. Beaufait and others (1977) show a weak dependence of duff consumption on upper duff moisture and the Buildup Index. Brown and others (1985) predict duff consumption on Montana clearcuts from measured duff moisture and predict moisture indices with variable success (correlation coefficients 0.48 to 0.76). The range of fuel moisture and preburn depths are considerably less than those prescribed for clearcut burns on the west side of the Cascade Range.

Table 1—Published equations predicting duff depth reduction from prescribed burns

Source, location, and species	Equation 1/	R^2	$s_{y \cdot x}$	N
Beaufait and others (1977), Montana, larch and Douglas-fir	DUFRED = -4.15 - 0.0022 UDMC - 0.05 BI + 1.31 $\sqrt{BI}$	0.53	1.2	76
Blackhall and AuClair (1982), northern British Columbia, white spruce and subalpine fir	DUFRED = -28.74 + 0.75 BEFDUFF + 2.78 LOGDMC + 9.63 LOGDC	.65	9	45
Brown and others (1985), Montana, larch and Douglas-fir	DUFRED = 2.61 - 0.023 LDMC + 0.42 BEFDUFF	.76	.8	60
Chrosciewicz (1978b), Manitoba, jack pine	DUFRED = 2.78 - 0.053 DMC; BEFDUFF less than 4 cm DUFRED = 9.22 - 0.094 DMC; BEFDUFF greater than 8 cm	.93 .90	.2 .4	10 5
Chrosciewicz (1978a), Saskatchewan, jack pine	DUFRED = 3.42 - 0.048 DMC; BEFDUFF = 4 cm DUFRED = 4.03 - 0.042 DMC; BEFDUFF = 6 cm	.74 .74	.3 .25	8 8
Sandberg (1980), Oregon and Washington, Douglas-fir and western hemlock	DUFRED = -0.16 + 1.76 $\sqrt{DRED}$ DUFRED = 6.67 - 0.13 NFDR-Th	.71 .78	.48 .47	11 10

1/ BEFDUFF = preburn duff depth in centimeters,
BI = Buildup Index,
DC = Drought Code,
DMC = Duff Moisture Code,
DRED = diameter reduction of woody fuels in centimeters,
DUFRED = duff depth reduction in centimeters,
NFDR-Th = moisture content of fuels larger than 7.6 cm predicted by the National Fire-Danger Rating System, in percent, and
UDMC (LDMC) = upper (lower) duff moisture content in percent.

Sandberg (1980) adapted Van Wagner's theory to underburning Douglas-fir in partial-cut stands in western Oregon and Washington. He predicts duff consumption from diameter reduction of large fuels ($r^2 = 0.78$) and from the National Fire-Danger Rating System (Deeming and others 1977) prediction of thousand-hour fuel moisture (NFDR-Th) ($r^2 = 0.78$). When applied to clearcuts, his predictors are not always successful (Little and Klock 1985, Little and others 1982). This may be the result of differences in temperature extremes and, hence, drying patterns on clearcuts versus partial cuts. Duff loadings on clearcuts are often more variable within a unit than in partial-cut stands. This is the result of large deposits of litter from crown material, increased disturbance from skid roads, and large amounts of rotten woody material incorporated in the duff from cull material left during felling and harvesting. Consequently, duff consumption on clearcuts is highly variable because of the high variability in duff loading, duff moisture, and fuel consumption (for example, large rotten logs that smolder for prolonged periods). There is a clear need for predictors of duff consumption that are tailored to clearcuts.

The Role of Loading and Consumption of Woody Fuel in Duff Consumption

Sandberg [2/] hypothesized that consumption of duff by fire is dependent on woody fuel consumption or woody fuel diameter reduction. When the duff bed is wet (NFDR-Th greater than 25 percent), total heat load (as measured by fuel consumption) will determine how much duff is consumed. By removing large fuels, the amount of fuel consumed will be reduced and, hence, the amount of duff consumed will also be reduced. When the duff bed is dry (NFDR-Th less than 25 percent), the upper duff serves as an insulating layer and reduces the penetration of heat into the duff. Under these conditions, the duration of fire (as measured by diameter reduction of large fuels) will determine how much duff is consumed. Fire duration is dependent on fuel moisture rather than on fuel loading.

Sandberg and Ottmar (1983) developed a set of equations that estimate the percentage of volume reduction by fire of large fuels in Douglas-fir and western hemlock units. The percentage of volume reduction (VRED) is based on the relationship between large fuel moisture (LGMC) and diameter reduction (DRED):

$$VRED = 1 - (d - DRED)^2 / d^2 \text{ , and}$$

$$DRED = 14.43 - 0.274\ LGMC \text{ ;}$$

where d is the root mean square diameter of large fuels in centimeters, DRED is calculated in centimeters, and LGMC is a percentage.

Removing larger material from a unit would decrease d. Although a greater proportion of the remaining fuel would be consumed for a given moisture content, the total amount of fuel before burn would be reduced, which would reduce total fuel consumption.

[2/]Unpublished Report, 1979, "Predicting prescribed fire behavior," by David V. Sandberg, U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, 4043 Roosevelt Way, NE, Seattle, WA 98105.

In a case study, a unit where all material larger than 0.15 by 1.8 m was removed prior to burning (leaving 9.1 Mg/ha of large fuels) had less duff consumption than the comparison unit, which was logged to 0.2 by 2.4 m (37.7 Mg/ha of large fuels) (Little and others 1982). In subsequent work by Little and Klock (1985), six paired units that were yarded to 0.1 by 1.2 m and 0.15 by 1.8 m and two units that were yarded to 0.2 by 2.4 m were broadcast burned. There was no apparent pattern in duff consumption relative to diameter reduction or fuel loading on these units.

Predicting Mineral Soil Exposed During Prescribed Fire

The amount of mineral soil exposed during a prescribed burn depends on the amount of duff cover, on the depth of duff prior to ignition, and on the depth of duff consumed during the burn. For those ecosystems with uniform duff densities and cover, mineral soil exposure—like duff consumption—will be closely tied to duff moisture content, fuel consumption, and weather variables. Chrosciewicz (1978a, 1978b) was not able to establish a significant relationship between mineral soil exposed and DMC for burns of jack pine clearcuts. Brown and others (1985) found mineral soil exposed to be correlated with lower duff moisture ($r^2 = 0.58$). The highest degree of success to date was achieved by Sandberg (1980). He related mineral soil exposed to NFDR-Th ($r^2=0.76$) for units with less than 10.5 cm of average duff depth (10 units in all).

Methods

This study was conducted to determine the combined influences of fuel loading and moisture on duff consumption. To isolate the separate effects of loading and moisture content, some units were divided into treatment blocks where either loading or moisture were varied within the unit. Other units with only one treatment were burned to expand our data base for larger fuel loadings.

We measured duff consumption on 38 treatment blocks on 15 cable-yarded clearcut units on National Forest (NF) and private lands in western Oregon and western Washington (fig. 1). The units spanned much of the geographical area and range of site conditions characteristic of the Douglas-fir zone. Elevation ranged from 400 to 1400 m; slope from zero to 35 percent. Douglas-fir and western hemlock comprised most of the slash on the units. Large fuel (greater than 7.6 cm diameter outside bark (d.o.b.)) loading ranged from 8.7 to 120.8 Mg/ha; fine fuel (less than 7.6 cm d.o.b.) loading ranged from 10.3 to 26.7 Mg/ha. Average duff depth ranged from 3.1 cm on a southwestern Oregon unit to over 17 cm on a western Washington unit (table 2).

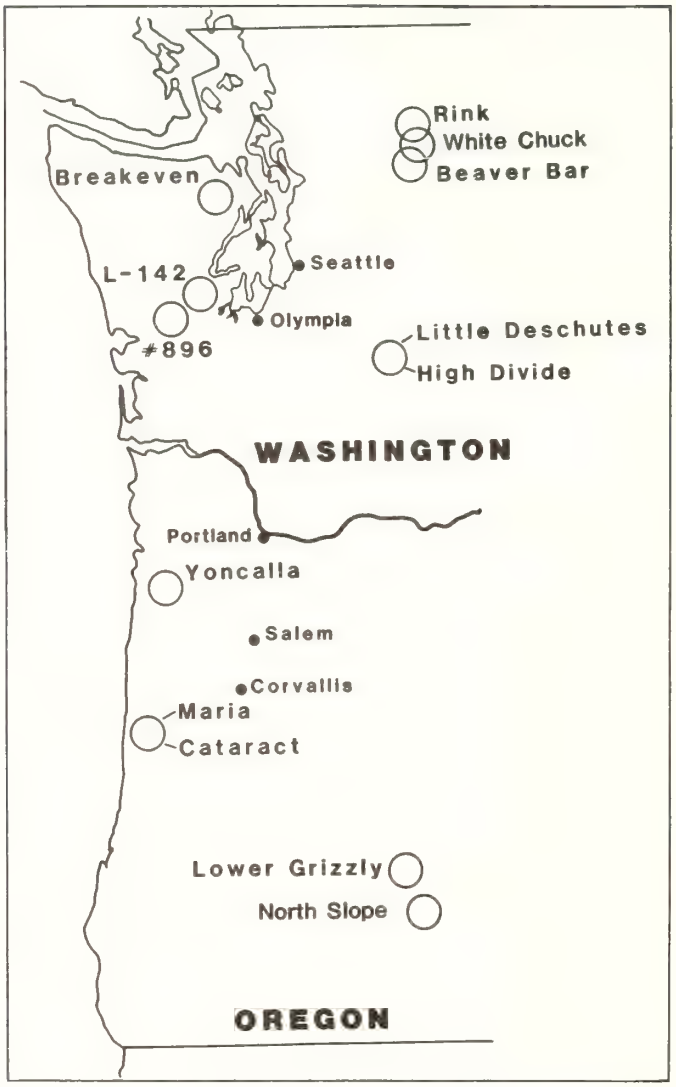

Figure 1.—Location of clearcut units in western Washington and western Oregon that were burned for the duff reduction study.

Table 2—Locations of units, fuel loadings, and date of burn

Unit name (location)	Block	Yarding specification	Preburn fuels: 0–7.6 cm d.o.b.	Preburn fuels: 7.6+ cm d.o.b.	Preburn fuels: Duff	Duff depth	Mineral soil exposed	Date burned
		m	Mg/ha	Mg/ha	Mg/ha	cm	percent	month-day-year
Cataract (Siuslaw NF)	1	0.1 x 1.2	16.1	8.7	86.5	6.5	17	8-19-83
	2	.15 x 1.8	24.2	19.7	92.6	6.5	11	8-19-83
	3	.2 x 2.4	15.0	34.3	89.7	7.7	22	8-19-83
	4	.2 x 2.4	17.9	54.2	137.4	9.7	6	9-17-83
Maria (Siuslaw NF)	1	.1 x 1.2	16.1	18.4	105.4	7.6	6	8-21-83
	2	.15 x 1.8	10.3	12.1	67.7	5.0	19	8-21-83
	3	.2 x 2.4	15.2	44.2	134.7	9.7	3	8-21-83
	4	.2 x 2.4	25.3	38.8	116.1	8.4	0	9-21-83
North Slope 6 (Rogue River NF)	1	.1 x 1.2	22.2	13.7	67.7	5.1	4	7-15-83
	2	.15 x 1.8	19.5	24.2	69.3	5.0	3	7-15-83
	3	.2 x 2.4	18.4	50.7	70.2	5.3	1	7-15-83
North Slope 7 (Rogue River NF)	1	.1 x 1.2	19.1	10.5	68.1	5.0	5	7-13-83
	2	.15 x 1.8	16.4	16.4	38.1	2.8	7	7-13-83
	3	.2 x 2.4	19.1	27.6	47.7	3.6	6	7-13-83
North Slope 8 (Rogue River NF)	1	.1 x 1.2	19.5	8.7	59.2	4.2	6	7-14-83
	2	.15 x 1.8	22.0	35.2	75.8	5.6	2	7-14-83
	3	.2 x 2.4	26.7	29.6	49.3	3.5	4	7-14-83
Lower Grizzly (Umpqua NF)	1	.1 x 1.2	13.7	9.6	72.6	5.1	9	7-24-83
	2	.15 x 1.8	24.0	31.2	100.7	7.4	5	7-24-83
	3	.2 x 2.4	19.7	44.6	140.1	9.7	5	7-24-83
	4	.2 x 2.4	22.6	34.5	95.7	6.8	3	9-29-83
Yoncalla (Siuslaw NF)	1	.1 x 1.2	15.0	30.3	72.9	5.3	10	9-23-83
	2	.15 x 1.8	15.0	25.1	67.3	5.1	18	9-23-83
	3	.2 x 2.4	22.4	52.1	106.3	7.6	4	9-23-83
	4	.2 x 2.4	12.6	24.2	79.6	5.7	4	9-23-83
White Chuck (Mount Baker-Snoqualmie NF)	1	***	24.2	34.3	157.6	11.2	2	7-09-84
	3	***	22.4	34.5	118.8	8.4	5	7-27-84
Breakeven (Olympic NF)	1	***	15.9	50.7	227.5	15.0	9	7-15-84
	2	***	16.4	42.8	209.8	13.4	0	8-26-84
	3	***	15.5	63.7	244.1	16.1	1	7-30-84
	4	***	21.1	60.1	181.1	12.1	5	7-15-84
Beaver Bar (Mount Baker-Snoqualmie NF)	1	***	17.3	62.1	175.3	12.0	10	8-23-84
Rink (Mount Baker-Snoqualmie NF)	1	***	23.3	120.2	125.8	8.8	9	9-19-84
L 142 (Olympic NF)	1	***	13.5	34.1	46.0	3.3	14	7-18-84
High Divide (Weyerhauser)		***	17.3	22.4	112.1	7.8	4	9-17-84
Little Deschutes (Weyerhauser)		***	18.2	32.7	136.7	9.9	0	7-06-84
Twin Harbors #896 (Weyerhauser)		***	17.7	58.3	124.0	8.6	7	7-23-84

*** = no yarding specification.
--- = not applicable.

We burned the seven clearcut units in Oregon in 1983 (Cataract, Maria, Yoncalla Dumbell—Siuslaw NF; North Slope #6, #7, and #8—Rogue River NF; and Lower Grizzly #5—Umpqua NF). Each unit was divided into treatment areas that were designed to vary the loading of large fuels while holding moisture content and fine fuel loading constant. In this way the effects of different loadings of large fuel on duff consumption could be isolated. We delineated three 0.2-ha treatment blocks on each clearcut unit. Each treatment block within a unit was cable yarded to one of three specifications chosen to cover the anticipated range of management options. All woody fuel larger than the specified piece size (0.10 by 1.2 m, 0.15 by 1.8 m, or 0.2 by 2.4 m) was removed from the block. We burned the three adjacent treatment blocks simultaneously to ensure similar fuel moisture conditions. A fourth block, yarded to 0.2 by 2.4 m (holdover), was established on four of these units (Cataract, Maria, Yoncalla Dumbell, and Lower Grizzly #5), and burned under moisture conditions different from the other three treatment blocks (fig. 2). We created no holdovers on the North Slope units because we expected that burning under dry conditions would result in nearly total consumption of the shallow duff layer.

We modified our sample design for the eight units burned in Washington in 1984 (Rink, Beaver Bar, and White Chuck Bench—Mount Baker-Snoqualmie NF; Breakeven and L142—Olympic NF; and High Divide, Little Deschutes, and Twin Harbor 896—Weyerhauser Timber Co.). Instead of altering fuel loading within a clearcut unit, we selected units with relatively consistent fuel loading and burned individual treatment blocks under different moisture conditions. We established 0.2-ha treatment blocks on two of the Washington units (four on Breakeven and three on White Chuck Bench) (fig. 2). Only one treatment block was established on each of the remaining units. The treatment blocks were burned at different times during the burning season to cover a range of moistures in large fuel.

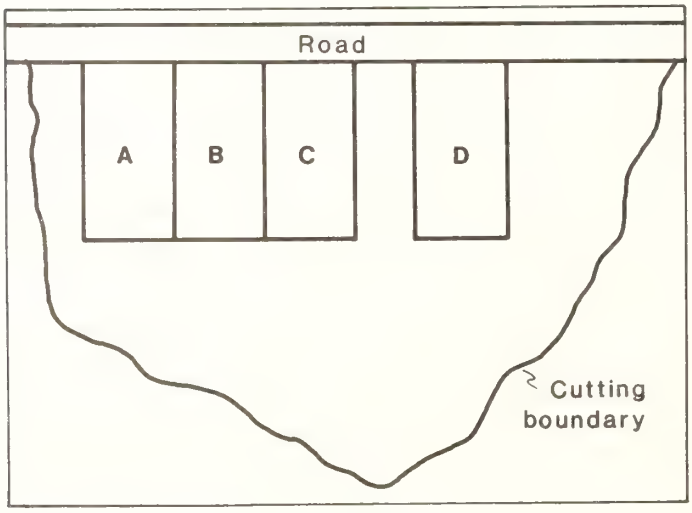

Figure 2.—Layout of treatment blocks within a cutting unit. In Oregon, A, B, and C burned simultaneously; D burned under different moisture conditions. In Washington, blocks burned under different moisture conditions.

We measured reduction in duff depth using procedures adapted from Beaufait and others (1977). We established 18 plots in a systematic grid to cover each treatment block. Around each plot we inserted 12 metal spikes and 4 tile pins [3/] flush with the top of the duff layer. Duff for our purposes included the litter, fermentation, and humus layers. We measured duff reduction as the length of spike or pin exposed after the burn. We measured preburn duff depth as the length of spike or pin above mineral soil.

Duff consumption was calculated for each pin by multiplying duff depth reduction by one of two bulk density factors: for duff derived from litter or for duff derived from rotten wood. To determine duff density factors on each of nine treatment blocks (Breakeven, White Chuck, Beaver Bar, and Rink units), we collected 27 duff samples from a systematic grid. At each sample location a 12.7-cm by 12.7-cm by 10.0-cm metal box with open ends was inserted into the ground so the top of the box was flush with the top of the duff layer. Duff to a depth of 10.0 cm or to mineral soil, whichever was less, was removed from the box. If the duff layer was less than 10.0 cm deep, we measured the depth at each of the four corners of the box. The volume of each sample was calculated as the average depth times the sample area (12.7 cm by 12.7 cm). The samples were air dried for 2 weeks at 20 °C and weighed to the nearest gram. The bulk density of each sample (grams per cubic centimeter) was calculated as sample weight divided by sample volume. We then calculated the average bulk density of (1) all samples from litter-derived duff and (2) all samples from duff derived from rotten wood. Duff loading and consumption were then calculated by multiplying the duff depth at each pin by the appropriate bulk density (0.129 g/cm^3 for litter or 0.160 g/cm^3 for rot).

Several variables thought to affect duff consumption were also measured. Loading of the large fuels was estimated from a planar intersect inventory (Brown 1974). The sampling density consisted of 15.25-m transects located on a systematic grid of 80 points. Consumption of large fuels was measured as diameter reduction of 40 randomly chosen logs on the transects. Wires were tightly wrapped around the logs before burning and cinched up after burning. The wire lengths were measured and converted to diameter reduction. Diameter reduction was converted to fuel consumption using Ottmar (1984). The consumption of fine fuels was calculated as the difference between preburn and postburn loading. We determined large fuel moisture by removing two cross sections from each wired log and weighing the sections before and after drying at 105 °C for 24 hours.

[3/] Tile pins were used to measure flaming and total duff consumption for a concurrent study.

Immediately prior to ignition of each treatment block we collected duff samples to determine the average percentage of moisture. We collected samples from the first 15 of the 18 plots in each treatment block. When a duff layer that was dry to the touch was present on top of a wet layer, we collected two samples—one from each layer—and measured the depth of the dry layer. If no distinct dry layer was present but duff dried with depth, we collected one sample each from the upper and lower half of the duff layer. When duff moisture seemed consistent throughout the profile (as is common with shallow duff layers), only one sample was taken on the plot. Each duff sample was a composite of samples collected from two locations within the plot area. On each plot, we sampled duff of similar kind (litter or rotten wood) and moisture content as that in which the duff pins were inserted. The samples were oven dried at 72 °C for 4 days to determine moisture content.

The treatment blocks were burned under a wide range of fuel moistures. We monitored environmental conditions using representative off-site Remote Automatic Weather Stations (RAWS) before burning each treatment block. Ignition of the 1983 units was delayed until the NFDR-Th was 25 percent or less and until days since last rain (1.3 cm or greater) were between 3 and 24 days. We believed this prescription would allow nearly complete consumption of fine fuels without allowing the duff to burn independently of large fuel. We burned the 1984 units over a range of fuel moisture conditions including spring (NFDR-Th greater than 25 percent), midsummer (NFDR-Th 22-25 percent), and late summer (NFDR-Th less than 22 percent). All burns were ignited by hand with strip head fires except the three Weyerhauser units, which were ignited using a helicopter. Data from the two sample designs, when pooled, provided information on duff consumption across a wide range of combinations of fuel loadings and moisture. A description of the 37 treatment blocks is presented in table 2. Moisture conditions at time of burn are shown in table 3.

Table 3—Moisture conditions at time of burn

Unit name (location)	Block	Moisture content at ignition: 7.6+ cm fuel	Upper duff	Lower duff	Dry layer depth	NFDR-Th	ADJ-Th	Days since rain
		percent			cm			
Cataract (Siuslaw NF)	1	27	24	129	2.3	25	36	36
	2	34	16	178	1.7	25	36	36
	3	29	31	184	2.3	25	36	36
	4	32	61	183	1.0	28	37	7
Maria (Siuslaw NF)	1	23	25	113	2.1	25	36	38
	2	23	21	129	2.0	25	36	38
	3	31	35	155	1.9	25	36	38
	4	37	45	169	1.1	26	36	3
North Slope 6 (Rogue River NF)	1	31	30	--	--	21	30	7
	2	34	25	--	--	21	30	7
	3	33	24	--	--	21	30	7
North Slope 7 (Rogue River NF)	1	32	52	201	1.8	21	30	5
	2	31	31	--	--	21	30	5
	3	34	40	--	--	21	30	5
North Slope 8 (Rogue River NF)	1	29	67	--	--	21	30	6
	2	31	83	--	--	21	30	6
	3	37	45	--	--	21	30	6
Lower Grizzly (Umpqua NF)	1	37	19	142	1.6	24	34	4
	2	40	25	168	1.2	24	34	4
	3	33	58	203	1.8	24	34	4
	4	40	70	--	--	20	28	30
Yoncalla (Siuslaw NF)	1	35	113	--	-	24	33	13
	2	34	117	--	--	24	33	13
	3	32	111	--	--	24	33	13
	4	31	100	--	--	24	33	13
White Chuck (Mount Baker-Snoqualmie NF)	1	35	204	263	--	24	34	9
	3	27	46	213	1.8	20	30	27
Breakeven (Olympic NF)	1	38	257	308	--	22	32	15
	2	23	20	231	3.8	19	27	57
	3	37	22	290	2.6	18	27	30
	4	37	241	291	--	22	32	15
Beaver Bar (Mount Baker-Snoqualmie NF)	1	35	25	246	3.4	18	27	54
Rink (Mount Baker-Snoqualmie NF)	1	31	97	242	--	25	31	7
L 142 (Olympic NF)	1	45	56	265	3.7	22	32	18
High Divide (Weyerhauser)		32	40	245	1.0	26	31	5
Little Deschutes (Weyerhauser)		31	49	221	1.5	25	35	6
Twin Harbors #896 (Weyerhauser)		23	16	213	2.9	21	30	23

--- = not applicable.

Analytical Methods

Predictive equations for duff consumption and mineral soil exposure were developed with multiple linear regression. All coefficients reported are significant at the 99-percent confidence level ($P = 0.01$). Blocks were treated as independent observations because duff and fuel loadings were not consistent for any one treatment. By assuming that these observations were independent, we may have underestimated the residual variance relative to what would exist if all observations were truly independent.

One treatment block, White Chuck Bench #2, was excluded from the analysis because fine fuels and duff were so wet that the burn would not carry. This left 37 treatment blocks for analysis.

Based on relationships previously published (table 1) and our own experience, we thought that preburn measures of loading and moisture content of large fuels and duff moisture would be useful in predicting duff consumption. We used days since significant rainfall as a simple indication of the amount of drying that had taken place in the duff. Based on Stocks (1970), we assumed that 1.3 cm of rain was needed to raise the moisture content of duff to 120 percent. The wetting of duff to that moisture content should require the input of heat from woody fuel to drive off moisture before ignition of the duff is possible (Sandberg 1980). The moisture content of large fuels as predicted by NFDR-Th and ADJ-Th (a refinement of NFDR-Th for application in the Douglas-fir region (Ottmar and Sandberg 1985)) was included in our analysis. Fuel consumption and diameter reduction of large fuels were also included in the analysis.

Results

The results presented here are the best fitting equations with regard to correlation coefficient and standard error for our data. We will first relate duff consumption to fuel loading and moisture content, then improve our predictive capabilities by dividing the data into subsets by moisture regimes. We consider variables that were not helpful in predicting duff consumption in the Discussion. Fuel and duff consumption and exposure of mineral soil for each block are listed in table 4.

Table 4—Effects of prescribed fire on consumption and diameter reduction of woody fuels, consumption and depth reduction of duff, and exposure of mineral soil

Unit name (location)	Block	Woody fuel			Duff		Mineral soil exposed
		0-7.6 cm consumed	>7.6 cm				
			Consumed	Diameter reduction	Consumed	Depth reduction	
		Mg/ha		cm	Mg/ha	cm	percent
Cataract (Siuslaw NF)	1	15.9	4.2	3.9	42.6	3.2	32
	2	23.8	5.8	2.6	37.4	2.7	23
	3	11.7	14.6	4.7	45.1	3.2	30
	4	17.3	21.3	4.9	44.6	3.3	17
Maria (Siuslaw NF)	1	15.9	10.1	5.2	59.0	4.4	35
	2	8.7	4.5	3.2	47.3	3.6	36
	3	14.8	21.1	7.0	70.6	5.2	27
	4	22.9	10.3	2.7	26.9	2.0	7
North Slope 6 (Rogue River NF)	1	22.0	10.3	5.9	31.4	2.4	17
	2	18.6	13.9	4.7	30.5	2.3	29
	3	18.2	28.5	5.5	49.3	3.7	33
North Slope 7 (Rogue River NF)	1	18.6	6.7	5.5	28.2	2.1	16
	2	15.9	9.2	4.6	17.5	1.3	27
	3	18.6	14.3	5.0	22.9	1.7	22
North Slope 8 (Rogue River NF)	1	19.5	7.8	7.2	18.6	1.4	24
	2	21.1	28.9	7.3	35.6	2.7	20
	3	26.7	18.4	5.0	26.2	2.0	29
Lower Grizzly (Umpqua NF)	1	11.0	1.6	1.2	11.4	.8	2
	2	20.6	12.6	4.0	16.8	1.3	4
	3	17.9	5.8	1.4	13.5	1.0	2
	4	22.6	16.6	5.1	51.1	3.8	21
Yoncalla (Siuslaw NF)	1	12.8	9.2	3.6	17.3	1.3	10
	2	9.6	11.2	4.1	19.5	1.5	6
	3	16.1	16.6	3.1	25.3	1.9	7
	4	11.0	2.5	1.0	20.8	1.6	18
White Chuck (Mount Baker-Snoqualmie NF)	1	22.2	7.6	1.6	13.0	.9	0
	3	16.1	9.2	2.4	37.2	2.7	17
Breakeven (Olympic NF)	1	13.7	8.5	4.5	23.8	1.6	4
	2	16.4	23.1	4.7	60.5	3.9	18
	3	15.5	11.0	1.7	48.6	3.2	5
	4	17.9	22.6	2.8	30.7	2.1	3
Beaver Bar (Mount Baker-Snoqualmie NF)	1	17.3	10.3	2.1	47.7	3.3	11
Rink (Mount Baker-Snoqualmie NF)	1	23.3	53.4	8.8	45.7	3.3	19
L 142 (Olympic NF)	1	11.4	3.4	1.2	24.9	1.8	27
High Divide (Weyerhauser)		17.3	6.3	2.2	20.0	1.4	9
Little Deschutes (Weyerhauser)		16.6	8.7	1.9	39.5	2.9	3
Twin Harbors #896 (Weyerhauser)		17.7	26.5	3.8	51.1	3.6	21

Predicting Duff Consumption

We were able to predict duff consumption from the amount of large fuel (greater than 7.62 cm d.o.b.), the moisture content of that fuel, and the number of days since 1.3 cm of rainfall with limited success:

$$DUFRED = 1.209 + 0.435\ L/LGMC + 0.044\ DAYS\ , \quad [1a]$$

$$R^2 = 0.53,\ s_{y \cdot x} = 0.76\ cm,\ n = 37;\ and$$

$$DUFCON = 14.70 + 6.98\ L/LGMC + 0.65\ DAYS\ , \quad [1b]$$

$$R^2 = 0.61,\ s_{y \cdot x} = 9.7\ Mg/ha,\ n = 37;$$

where: DUFRED = duff depth reduction in centimeters,
DUFCON = duff consumption in megagrams per hectare,
L = preburn loading of large fuel in megagrams per hectare,
LGMC = moisture content of fuel 7.64 to 22.86 cm d.o.b. in percent, and
DAYS = the number of days since 1.3 cm of rainfall.

A graphic analysis indicated that two populations existed within our data set (fig. 3). Those units burned more than 25 days after 1.3 cm of rainfall from an individual storm system had more duff consumed for a given loading and moisture content of large fuels than those that were burned less than 25 days since rain. A linear regression using a dummy variable to designate the two groups showed a significant difference in intercept but not in slope (fig. 4):

$$DUFRED = 2.91 + 0.572\ L/LGMC - 1.54\ X\ , \quad [2a]$$

$$R^2 = 0.60,\ s_{y \cdot x} = 0.70\ cm,\ n = 37;\ and$$

$$DUFCON = 39.39 + 9.03\ L/LGMC - 22.26\ X\ , \quad [2b]$$

$$R^2 = 0.66,\ s_{y \cdot x} = 9.0\ Mg/ha,\ n = 37;$$

where: $X = 1$ when days since rain were less than 25; otherwise, $X = 0$.

The term L/LGMC is an approximation of the amount of fuel that is available to provide heat to dry and ignite the duff during a burn. Fuel consumption is a more direct measure of this heat. Our predictive power was improved by using fuel consumption as the independent variable (fig. 5):

$$DUFRED = 2.905 + 0.056\ LGCON - 1.691\ X\ , \quad [3a]$$

$$R^2 = 0.72,\ s_{y \cdot x} = 0.59\ cm,\ n = 37;\ and$$

$$DUFCON = 40.36 + 0.791\ LGCON - 24.39\ X\ , \quad [3b]$$

$$R^2 = 0.75,\ s_{y \cdot x} = 7.7\ Mg/ha,\ n = 37;$$

where: LGCON = consumption of fuel larger than 7.62 cm d.o.b. in megagrams per hectare (Mg/ha), and

X = 1 when days since rain were less than 25, otherwise; X = 0.

LGCON can be predicted from algorithms presented by Sandberg and Ottmar (1983).

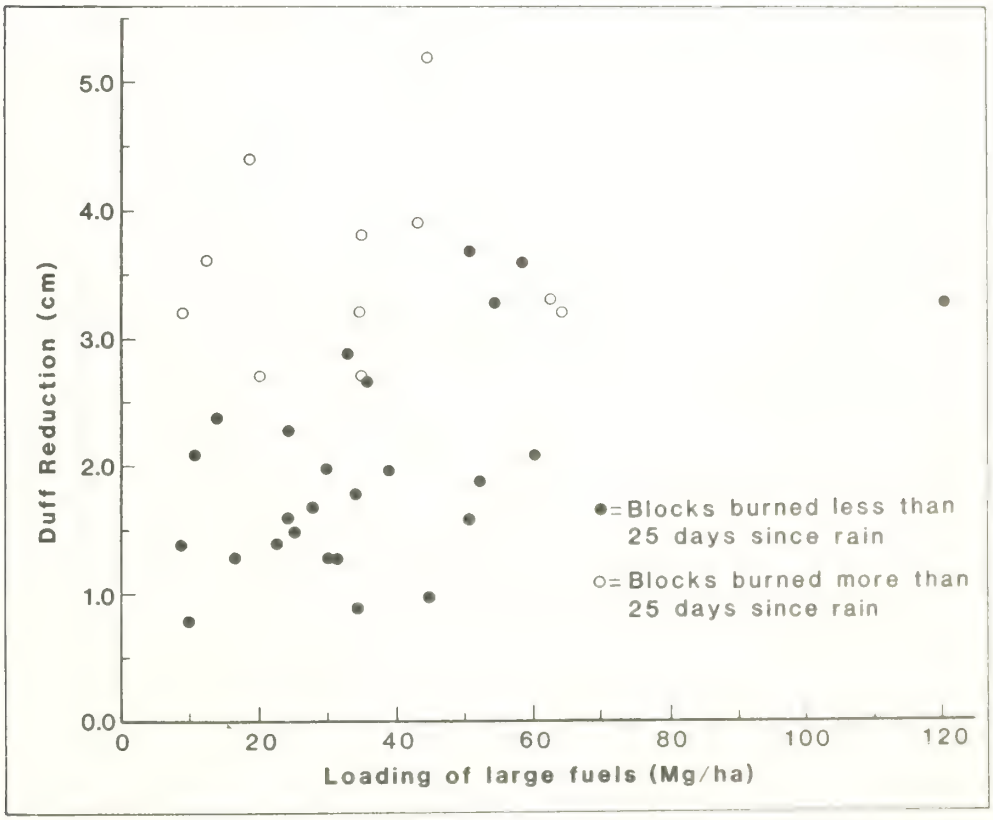

Figure 3.—Relationship of duff reduction and loading of large fuels.

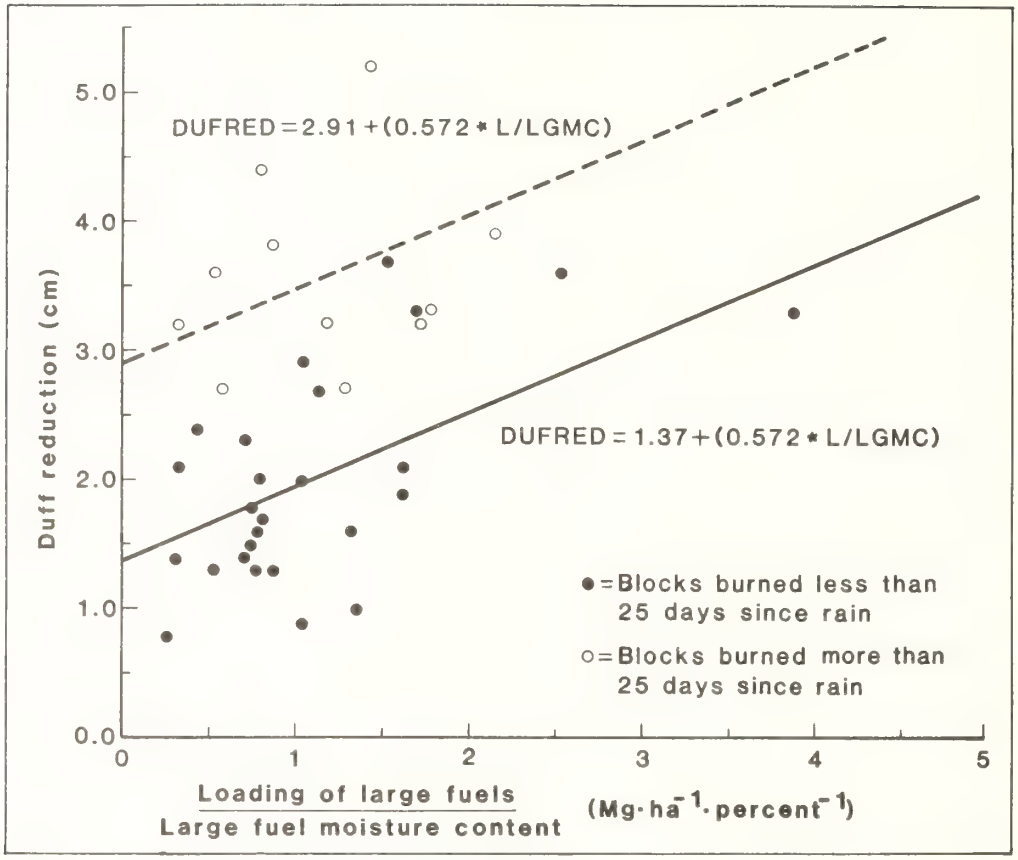

Figure 4.—Relationship of duff reduction, loading, and moisture content of large woody fuels (greater than 7.62 cm d.o.b.).

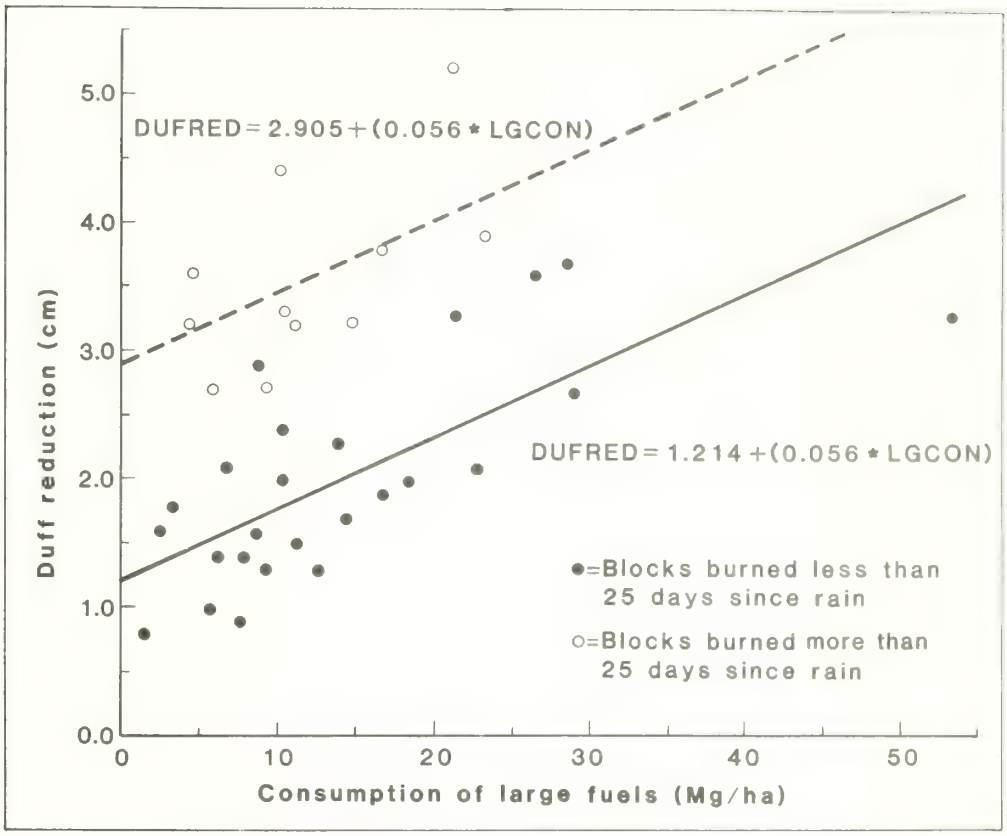

Figure 5.—Relationship of duff reduction and consumption of large fuels.

Equations were then developed separately for both groups. Duff consumption was predicted from large fuel consumption for the first group (less than 25 days since rainfall). Duff consumption for the second group (25 or more days since rainfall) was correlated more strongly with fire duration, as measured by fuel diameter reduction, than with fuel consumption.

The following equations predict duff consumption for units where consumption is dependent on moisture and consumption of large woody fuels (less than 25 days since rain):

$$DUFRED = 1.295 + 1.659\ LGCON/LGMC\ , \quad [4a]$$

$$R^2 = 0.58,\ s_{y \cdot x} = 0.57\ cm,\ n = 26;\ and$$

$$DUFCON = 17.01 + 23.26\ LGCON/LGMC\ , \quad [4b]$$

$$R^2 = 0.60,\ s_{y \cdot x} = 7.7\ Mg/ha,\ n = 26.$$

The presence or absence of a distinct upper dry layer in the duff also influenced the amount of duff consumed. A further split based on moisture profile gave the following results.

For units **without** a distinct dry layer of duff:

$$DUFRED = 1.020 + 2.186\ LGCON/LGMC\ , \quad [5a]$$

$$R^2 = 0.58,\ s_{y \cdot x} = 0.45\ cm,\ n = 16;\ and$$

$$DUFCON = 13.89 + 29.03\ LGCON/LGMC\ , \quad [5b]$$

$$R^2 = 0.59,\ s_{y \cdot x} = 5.8\ Mg/ha,\ n = 16.$$

For units **with** a distinct dry layer:

$$DUFRED = 1.159 + 1.316\ LGCON/LGMC + 0.041\ DAYS\ , \quad [6a]$$

$$R^2 = 0.65,\ s_{y \cdot x} = 0.70\ cm,\ n = 10;\ and$$

$$DUFCON = 15.26 + 18.35\ LGCON/LGMC + 0.64 DAYS\ , \quad [6b]$$

$$R^2 = 0.68,\ s_{y \cdot x} = 9.4\ Mg/ha,\ n = 10.$$

For units where consumption was dependent on fuel moisture (more than 25 days since rain), duff consumption was predicted from the square root of the diameter reduction of the large fuels (DRED):

$$DUFRED = 0.839 + 1.413\ \sqrt{DRED}\ , \quad [7a]$$

$$R^2 = 0.64,\ s_{y \cdot x} = 0.47\ cm,\ n = 11;\ and$$

$$DUFCON = 16.19 + 17.41\ \sqrt{DRED}\ , \quad [7b]$$

$$R^2 = 0.51,\ s_{y \cdot x} = 7.5\ Mg/ha,\ n = 11;$$

where: DRED is measured in centimeters.

We were not able to predict duff consumption from either the NFDR-Th or ADJ-Th fuel moisture estimates or from the measured fuel moisture (R^2 less than 0.2).

Predicting the Amount of Soil Exposed by Burning

The amount of soil exposed after a burn depends on the amount of soil exposed before the burn, the depth of the duff covering the rest of the soil, and the amount of duff consumed during the fire. We were able to predict soil exposed from average duff depth before burn and the number of days since last rainfall:

$$\%EXPOSED = 28.0 - 2.4\ BEFDUFF + 0.43\ DAYS\ , \quad [8]$$

$$R^2 = 0.58,\ s_{y \cdot x} = 7.2 \text{ percent},\ n = 37;$$

where: %EXPOSED = the amount of mineral soil exposed during the burn,
BEFDUFF = the average duff depth before burn in centimeters, and
DAYS = the number of days since 1.3 cm of rainfall.

Deeper duff depths will have a minimal amount of soil exposed by the burn. For example, for a unit with a preburn duff depth of 16 cm (the upper end of our data range), more than 25 days since rain must elapse before any additional soil is exposed. Our predictive capabilities were not improved by adding preburn soil exposure or loading to the equation.

Discussion

We were successful in predicting duff consumption from preburn loading and moisture content of large fuels and days since rainfall. As expected, when the duff was wet, duff consumption could be predicted from fuel consumption. As the duff dried, consumption was more dependent on fire duration, as measured by diameter reduction of large fuels. We were able to improve our predictive power by dividing the data set into those units where duff reduction was dependent on fuel consumption and those where it was dependent on fire duration based on the number of days since significant precipitation. We also separated the units that were dependent on fuel consumption into those with and those without a distinct upper dry layer of duff. We were not able to predict duff reduction directly from preburn loading for all groups.

We did not stratify the selection of units by these classifications. By selecting a subsample of the data instead of sampling units by class, we may have biased samples within the classes. The scope of inference for equations 3-7 is thereby reduced. The reader is cautioned to consider the range of data for which each equation was developed.

The predictive power of the equations presented here are within the range for those previously published. We can only make a direct comparison of duff depth reduction with Sandberg (1980) for those units burned more than 25 days since rain. Although our correlation coefficient is not as high as his, the standard error is similar for the same sample size.

Although we sampled for duff moisture on all blocks and obtained satisfactory estimates of average duff moisture for the blocks, neither upper nor lower duff moisture appeared to enhance our ability to predict duff consumption. We suspect that this was due to the high variability of duff moisture within a treatment block. Duff moisture data might prove useful if they were in frequency form and were linked with duff depth and bulk density information for individual samples.

We were not able to show a correlation of duff consumption with NFDR-Th or ADJ-Th because our data did not span a large enough range of predicted moisture contents of woody fuels. Predicted moisture content of large fuels was purposefully constrained in the Oregon units to isolate effects of fuel loading. Several of the blocks in Washington had no slope, which reduced the amount of consumption of large fuel that would be expected for a given NFDR-Th based on Sandberg and Ottmar (1983).

Moisture content and consumption of large fuels were estimated from measuements taken at the study areas. If predicted values for these variables are used in the equations (such as values obtained through the National Fire-Danger Rating System), other sources of error will be introduced into the equations beyond what we report here. Use of predicted values should reduce the confidence one has in the resulting estimate of duff reduction or consumption.

We were not able to significantly reduce error by omitting those pins that were in mineral soil, in stumps, or in logs before burn. This is probably because of the high variability of duff depth and density across a unit.

The equations presented in this paper should be used under the conditions they were developed for. These equations cover units with average duff depth greater than 3 cm. For units with shallow duff layers, duff moisture will be drier and more consistent over the unit. The number of days since rain that separates our first population (loading dependent) from our second (moisture dependent) will be less than 25. Duff reduction on units with shallow duff depths may be predictable from Sandberg's (1980) equations using NFDR-Th.

We have not incorporated data for extremes in fuel and duff moisture. Under very dry conditions, when the upper 5 cm of duff has less than a 30-percent moisture content, the duff will burn independently of the surface fuels. Under very moist conditions, much of the area will not ignite and the smoldering period will be reduced. Sustained dry winds or precipitation during the burn will have similar effects.

Application

Forest managers need the ability to predict duff reduction and mineral soil exposure to meet objectives for site preparation and productivity. The amount of duff consumed during a prescribed fire depends on loading and moisture content of woody fuels, the moisture profile of the duff, and the duration of heat supplied to the duff by the burning woody fuel. Managers can meet their objectives by (1) specifying the amount of woody fuels to remain on site after harvest, (2) scheduling the burn for specific fuel moistures, or (3) using a combination of both (1) and (2). Equation 2 can be used to evaluate the effect of removing large fuels before burn on subsequent duff consumption. Equation 4 can be used to set prescriptions once a given fuel loading is determined. Equations 5, 6, and 7 can be used to predict duff consumption on a unit for a particular day. Three management scenarios for a hypothetical clearcut unit are presented below to demonstrate the use of these equations.

Hypothetical Clearcut Unit

Location: Mount Hood National Forest
Slope: 30 percent
Aspect: west
Average duff depth: 9.1 cm
Mineral soil exposure: 20 percent
Fuel type: Douglas-fir/western hemlock
Woody fuels: all material larger than 20.3 by 240 cm has been removed
Fuel loading:

Size class		Dry weight		Root mean square diameter (d)	
cm	in	Mg/ha	tons/acre	cm	in
0-7.6	0-3	14.4	6.4		
7.6-15.2	3-6	11.9	5.3		
15.2-22.9	6-9	11.2	5.0		
22.9-50.8	9-20	54.5	24.3		
50.8+	20+	30.0	13.4		
All 7.6+	All 3+	107.6	48.1	18.0	7.1
All woody fuels		122.0	54.4		
Duff		150.2	67.0		
Total fuel loading		272.0	121.3		

Scenario 1: Influence woody fuel loading to achieve management objectives.—The manager can affect duff reduction by altering the loading of large woody fuels. For example, suppose the hypothetical unit is burned 15 days after rainfall with its present fuel loading and with large fuel moisture content at 28 percent. Equation 2a shows that duff depth would be reduced by 3.6 cm:

$$\begin{aligned} \text{DUFRED} &= 2.91 + 0.572\ \text{L/LGMC} - 1.54\text{X} \\ &= 2.91 + 0.572\ (107.6/28) - 1.54 \\ &= 3.6\ \text{cm}. \end{aligned} \qquad [2a]$$

The loading of large woody fuels can be reduced by yarding all pieces larger than a specified size (for example, 10 by 131 cm) from the unit. Because piece size is specified in terms of length as well as diameter, and length is rarely measured in fuel inventories, one cannot predict the exact weight of fuels that would remain on the unit following yarding. In this example, we assume that 60 percent of the large fuel is removed, which reduces loading from 107.6 Mg/ha to 43.0 Mg/ha. Burning under the same moisture conditions as in the previous example would result in a reduction in duff depth of 2.2 cm—1.4 cm less than with the original fuel loading:

$$\begin{aligned} \text{DUFRED} &= 2.91 + 0.572\ \text{L/LGMC} - 1.54\text{X} \\ &= 2.91 + 0.572\ (43.0/28) - 1.54 \\ &= 2.2\ \text{cm}. \end{aligned} \qquad [2a]$$

Scenario 2: Influence moisture conditions to achieve objectives.—The manager can also affect duff reduction by influencing the moisture conditions the unit is burned under. This can be accomplished by burning a specified number of days after rainfall or by burning when large woody fuels have a specific moisture content.

1. Management objective: Retain an average duff depth of 5 cm.—The manager can use equation 4a to determine the lowest fuel moisture under which the burn can take place and still meet objectives. Because we want to retain an average duff depth of at least 5 cm, our goal is to reduce duff depth by no more than 4.1 cm ((maximum duff reduction during the burn) = (preburn duff depth) - (postburn duff depth) = 9.1 - 5.0 = 4.1 cm):

$$\text{DUFRED} = 1.295 + 1.659\ \text{LGCON/LGMC}\ ; \qquad [4a]$$

where: LGCON = L x VRED,
VRED = $1 - (d - \text{DRED})^2/d^2$ (Sandberg and Ottmar 1983),
DRED = 14.43 - 0.274 LGMC (Sandberg and Ottmar 1983),
d = 12.0 cm (reduced from 18.0 cm by yarding), and
L = 43.0 Mg/ha (reduced from 107.6 cm by yarding—see scenario 1).

For LGMC = 20 percent:
DRED = 9.0 cm,
VRED = 0.94,
LGCON = 43.0 x 0.94 = 40.4 Mg/ha, and
DUFRED = 4.6 cm.

For LGMC = 35 percent:
DRED = 4.8 cm,
VRED = 0.64,
LGCON = 43.0 x 0.64 = 27.5 Mg/ha, and
DUFRED = 2.6 cm.

For LGMC = 23 percent:
DRED = 8.1 cm,
VRED = 0.89,
LGCON = 43.0 x 0.89 = 38.3 Mg/ha, and
DUFRED = 4.1 cm.

To meet the management objective in this example, the burn must take place when large woody fuel moisture is at least 23 percent. If it does not, duff depth will be reduced by more than the desired 4.1 cm, which will result in an average duff depth on the unit of less than 5 cm.

2. Management objective: Remove 5 cm of duff to ensure that seedlings are planted with their roots in mineral soil.—Suppose our example unit has an average duff depth of 15 cm. Local experience has led the manager to believe that planting crews do not do an adequate job when average duff depth exceeds 10 cm. One of the objectives for burning this unit is to reduce duff depth by 5 cm. However, large fuel moistures seldom get below 18 percent during the burn season in this area. Can this objective be met if moisture content of large fuels is larger than 18 percent?

For LGMC = 18 percent:
DRED = 9.0 cm,
VRED = 0.94,
LGCON = 43.0 x 0.94 = 40.4 Mg/ha, and
DUFRED = 1.295 + 1.659 (40.4/18) = 5.1 cm.

The manager's chances of obtaining the desired amount of duff consumption are low. Had the unit not been gross yarded, the chances of reducing the duff layer by 5 cm would have been much better:

For LGMC = 28 percent:
DRED = 6.8 cm,
VRED = $1 - (18 - 6.8)^2/18^2 = 0.61$,
LGCON = 107.6 x 0.61 = 65.6 Mg/ha, and
DUFRED = 1.295 + 1.659 (65.6/28) = 4.9 cm.

Scenario 3: Predict the effects of burning out of prescription.—It is not unusual for regulatory agencies to permit burning on days when priority units are not in prescription. The manager can use either equation 4a or 7a to determine the magnitude of effects from burning out of prescription. In this case, the manager cannot alter either fuel loading or moisture. If the unit had rain less than 25 days ago, the manager would use equation 4a to predict duff depth reduction. The effect of burning our example unit at 20 days since rain with a fuel moisture of 20 percent would be a reduction of duff depth of 4.6 cm (see calculations under scenario 2, management objective 1).

If 25 or more days have elapsed since rainfall, equation 7a can be used to predict duff reduction. For example, if large woody fuel moisture content is 18 percent and the unit is burned 30 days after rainfall, duff depth would be reduced by 5.2 cm:

$$\begin{aligned} \sqrt{\text{DRED}} &= \sqrt{14.43 - 0.274\ \text{LGMC}} \\ &= 3.1\ \text{cm; and} \end{aligned}$$

$$\begin{aligned} \text{DUFRED} &= 0.839 + 1.413\ \sqrt{\text{DRED}} \\ &= 0.839 + 1.413\ (3.1) \\ &= 5.2\ \text{cm.} \end{aligned} \qquad [7a]$$

Under these conditions, mineral soil would be exposed on 19 percent of the unit during the burn, resulting in a total postburn exposure of 39 percent:

$$\begin{aligned} \%\ \text{EXPOSED} &= 28.0 - 2.4\ \text{BEFDUFF} + 0.43\ \text{DAYS} \\ &= 28.0 - 2.4\ (9.1) + 0.43\ (30) \\ &= 19\ \text{percent.} \end{aligned} \qquad [8]$$

Conclusions

Our results suggested that duff consumption from prescribed fire can be reduced by reducing fuel loading before burning, by burning under moist conditions, or both. In some areas, smoke management concerns allow for relatively few days to burn clearcuts during the year. In those cases, removing additional woody fuel during or after harvest will broaden the moisture conditions under which prescriptions for duff consumption can be met and, hence, allow the manager more flexibility in scheduling burns. Costs of wood removal may be offset by reductions in costs of burning and mitigation of negative effects of burning out of prescription. For the range of conditions in this study, the effect of fuel loading on duff consumption decreased with the number of days since rainfall. The amount of duff consumed during burns conducted more than 25 days since rain was dependent on fire duration, as measured by diameter reduction of large fuels, and hence, was dependent on the moisture content of large woody fuels.

Acknowledgments

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English Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.3937	inches
Meters (m)	3.2808	feet
Hectares (ha)	2.4711	acres
Grams (g)	0.0350	ounces
Kilograms (kg)	2.2046	pounds
Kilograms/hectare (kg/ha)	0.8926	pounds/acre
Megagrams/hectare (Mg/ha)	0.4453	tons/acre
Celsius	1.8 then add 32	Fahrenheit

Equations in English Units

DUFRED = 0.48 + 0.38 L/LGMC + 0.02 DAYS , and [1a]

DUFCON = 6.56 + 6.98 L/LGMC + 0.29 DAYS ; [1b]

where: DUFRED = duff depth reduction in inches,
DUFCON = duff consumption in tons per acre,
L = preburn loading of large fuel in tons per acre,
LGMC = moisture content of fuel 3.1 to 9.0 inches d.o.b. in percent, and
DAYS = days since continuous rainfall greater than 0.5 in.

DUFRED = 1.14 + 0.51 L/LGMC - 0.61 X , and [2a]

DUFCON = 17.57 + 9.03 L/LGMC - 9.91 X ; and [2b]

DUFRED = 1.14 + 0.05 LGCON - 0.67 X , and [3a]

DUFCON = 18.00 + 0.79 LGCON - 10.88 X ; [3b]

where: LGCON = consumption of fuel larger than 3.0 inches d.o.b. in tons per acre, and
X = 1 when days since rain were less than 25;otherwise, X = 0.

The following equations predict duff consumption for units where consumption is independent of fuel loading (less than 25 days since rain):

DUFRED = 0.51 + 1.46 LGCON/LGMC , and [4a]

DUFCON = 7.59 + 23.26 LGCON/LGMC . [4b]

For units **without** a dry layer of duff:

DUFRED = 0.40 + 1.93 LGCON/LGMC , and [5a]

DUFCON = 6.20 + 29.03 LGCON/LGMC . [5b]

For units **with** a distinct dry layer:

DUFRED = 0.46 +1.16 LGCON/LGMC + 0.02 DAYS , and [6a]

DUFCON = 6.81 + 18.35 LGCON/LGMC + 0.29 DAYS . [6b]

For units where consumption is dependent on fuel moisture (more than 25 days since rain), duff consumption can be predicted from the square root of the diameter reduction of the large fuels (DRED):

$$DUFRED = 0.33 + 2.80 \sqrt{DRED}\text{ , and} \quad [7a]$$

$$DUFCON = 7.22 + 39.14 \sqrt{DRED}\text{ ;} \quad [7b]$$

where DRED is measured in inches.

Predicting the amount of soil exposed by burning:

$$\%EXPOSED = 25.77 - 8.71\ BEFDUFF + 0.43\ DAYS\text{ ;} \quad [8]$$

where BEFDUFF is the average duff depth before burning, in inches.

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Abbreviations

ADJ-Th—predicted moisture content of large fuels adjusted for Douglas-fir

BEFDUFF—average depth of duff before burn in millimeters.

DAYS—days since at least 1.3 cm of rainfall within a 24-hour period.

DMC—Canadian Duff Moisture Index.

DRED—diameter reduction of fuels greater than 7.6 cm d.o.b.

DRYDEPTH—depth of the distinct dry layer of duff.

DUFCON—consumption of duff during burn in megagrams per hectare.

DUFRED—reduction in average duff depth due to burn.

%EXPOSED—the percentage of area on a unit where the A-horizon is exposed by consumption of duff during the burn.

L—loading of fuels larger than 7.6 cm d.o.b. before burn.

LGCON—consumption of fuels greater than 7.6 cm d.o.b. in megagrams per hectare.

LGMC—measured moisture content of large fuels at time of burn in percent.

NFDR-Th—predicted moisture content of large fuels from National Fire-Danger Rating System in percent.

UDMC—measured moisture content of the upper layer of duff in percent. The upper layer is either the pronounced dry layer or the upper half of the duff depending on the presence or lack of a dry layer.

VRED—volume reduction of large fuels in percent.

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Little, Susan N.; Ottmar, Roger D.; Ohmann, Janet L. Predicting duff consumption from prescribed burns on conifer clearcuts in western Oregon and western Washington. Res. Pap. PNW-362. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 29 p.

Duff consumption by fire was studied on 15 cable-yarded clearcut units in western Oregon and western Washington. Equations are presented that predict duff consumption (in depth reduction and weight loss) from loading, consumption, and moisture of large fuels, and days since significant precipitation. When more than 25 days elapsed since 1.3 cm rainfall, the effect of large fuel loading on duff consumption diminished. Duff consumption was dependent on the diameter reduction of large fuels when there had been no rain for at least 25 days. The results indicated that duff consumption can be reduced by removing large fuel before the burn, scheduling the burn under moist conditions, or both. Methods are demonstrated to prescribe the proper level of fuel removal and moisture regime at time of burn to achieve a given level of duff consumption.

Keywords: Duff consumption, duff reduction, fire effects, prescribed burning, duff moisture, mineral soils, clearcuts.

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July 1986

OKLAHOMA'S Forest Products Industry: Performance and Contribution to the State's Economy, 1970 to 1980

Wilbur R. Maki, Con H Schallau, Bennett B. Foster, and Clair H. Redmond

Abbreviations

States

AL	Alabama
AR	Arkansas
FL	Florida
GA	Georgia
KY	Kentucky
LA	Louisiana
MS	Mississippi
NC	North Carolina
OK	Oklahoma
SC	South Carolina
TN	Tennessee
TX	Texas
VA	Virginia
SO	South
US	United States

Industries

FPI	Forest Products Industry
LWP	Lumber and Wood Products
PAP	Paper and Allied Products
WF	Wood Furniture

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Abstract

Maki, Wilbur R.; Schallau, Con H; Foster, Bennett B.; Redmond, Clair H. Oklahoma's forest products industry: performance and contribution to the State's economy, 1970 to 1980. Res. Pap. PNW-363. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

Employment and earnings in Oklahoma's forest products industry, like those of most Southern States, grew significantly between 1970 and 1980. In fact, Oklahoma's share of the Nation's forest products employment and earnings increased during this period. In 1980, lumber and wood products accounted for the largest share of the industry's employment, but paper and allied products had a larger share of the earnings. In 1977, pulp and allied products had higher productivity than either lumber and wood products or wood furniture.

Keywords: Forest products industries, economics (forest products industries), employment (forest products industries), Oklahoma.

Preface

Oklahoma's forest products industry, with the exception of wood furniture, experienced significant growth during the 1970's. To varying degrees, this growth reflects the increased investment in new plants and equipment and a growing demand for Oklahoma's forest products.

This report briefly describes Oklahoma's forest products industry—its composition, location, evolution, and relation to economic activity elsewhere in the State, the South, and the Nation.

Estimates of employment and earnings shown in this report were derived from U.S. Department of Commerce data. All references to dollar amounts are in constant 1977 dollars.

This is one in a series of reports for each of the 13 Southern States. These reports are companions to an analysis of the changing roles of the forest products industries of the South and the Pacific Northwest.

Highlights

- Between 1970 and 1980, Oklahoma's employment in the forest products industry—wood furniture, lumber and wood products, and paper and allied products—grew at a faster rate than the Nation's all-industry average (57 percent and 22 percent, respectively). Oklahoma's total earnings in the forest products industry nearly doubled, while the Nation's earnings increased by 27 percent.

- During the 1970's, Oklahoma's forest products industry increased its share of the Nation's employment and earnings in the forest products industry. Above average growth accounted for this performance. In 1980, for instance, Oklahoma had 2,500 more employees than it would have had if it had grown at the average rate for the industry between 1970 and 1980.

- The forest products industry was an important component of the economic base of several counties in southeastern Oklahoma, and its importance increased in these areas during the 1970's.

- Paper and allied products accounted for the largest share of value added in 1977 and was the fastest growing segment of Oklahoma's forest products industry in terms of employment and earnings. These changes reflect the construction of new processing facilities at the beginning of the decade.

- In 1977, average profits before taxes per worker hour (a commonly used measure of productivity) of Oklahoma's forest products industry were higher than those for most Southern States. Only 3 of the 13 Southern States had higher productivity.

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The Forest Products Economy of Oklahoma

The State's Work Force

Oklahoma's estimated full- and part-time work force in 1980 was comprised of an estimated 1.4 million employees and proprietors (see appendix 1, table 1, for sources of employment and earnings data). Oklahoma's work force grew considerably faster between 1970 and 1980 than did the national average (35.7 versus 22.3 percent). Total earnings—wage and salary payments and proprietorial income—also grew faster than the national average. Measured in constant 1977 dollars, the State's earnings increased by 37.0 percent compared with 27.4 percent for the Nation. As can be seen in the following tabulation, services, retail trade, manufacturing, and State and local government were the State's four largest employer categories:

	Percent of total employment, 1980	
Employers	**Oklahoma**	**U.S.**
Major industries:		
Services	14.70	18.22
Retail trade	13.61	14.18
Manufacturing (including forest products industry[1/])	13.35	19.15
State and local government	13.27	12.56
Nonfarm proprietors	7.89	6.58
Agriculture	7.65	4.39
Mining	5.07	0.97
Transportation, communication, and public utilities	4.91	4.84
Wholesale trade	4.88	4.97
Finance, insurance, and real estate	4.09	4.95
Construction	3.98	4.08
Federal civilian	3.36	2.81
Federal military	3.24	2.30
Total	100.00	100.00

[1/]The forest products industry is comprised of (1) lumber and wood products (SIC 24), except mobile homes (SIC 2451); and (2) wood furniture manufacturing (SIC 2511, 2512, 2517, 2521, 2541) and paper and allied products (SIC 26).

Components of the State's Economic Base

Along with total employment there is another and perhaps more important way to judge an industry's contribution to Oklahoma's economy. For the State's economy to grow and develop, it must attract new dollars so residents can buy goods and services produced elsewhere. The industries that export products and services beyond local boundaries (that is, to elsewhere in the State, to other States, and to the world) and bring in new dollars constitute the area's economic base. Generally speaking, most manufacturing employment is classified as "economic base" (or "basic"); residentiary employment (for example, barber shops, realty firms, schools, and local government) is primarily geared to producing for local needs. Some services, however, may be basic; for example, Federal military provides national defense for all the Nation's citizens, and taxpayers outside Oklahoma provide financial support for this activity.

Residentiary employment is supported by the economic base. Money flowing in provides income for wage earners and entrepreneurs to spend on locally purchased goods and services. In most cases, the economic growth of a region is dependent on the success of its economic base.

We used the excess employment technique to identify the industries that comprise Oklahoma's (or sub-State district's) economic base. This approach accepts the national distribution of employment among industries as a norm. Any industry with employment in excess of this norm is considered to be producing for export markets outside the State (or sub-State district) and is part of Oklahoma's economic base. The percentage of Oklahoma's excess employment served as an indicator of the State's dependency on a particular industry for generating new dollars from outside the State (table 2 shows how excess employment and industry dependency indicators for Oklahoma were calculated). A particular industry may be basic at the local level but not at the State level.

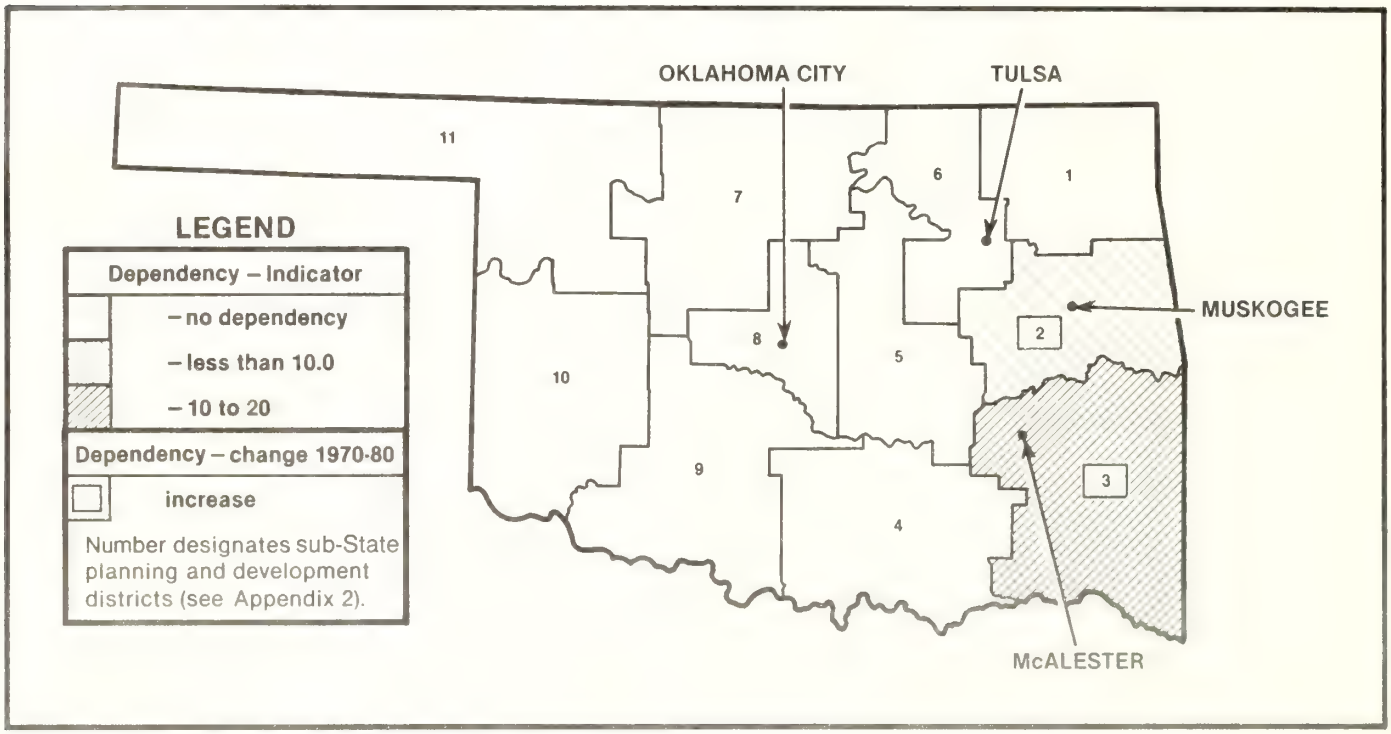
In 1980, 10 industries accounted for 94.8 percent of the State's excess employment—that is, its economic base (see tabulation below). Though these same industries accounted for only a slightly larger share (95.8 percent) in 1970, the change in shares of certain individual industries is noteworthy. In 1970, agriculture was the largest component of the State's economic base. By the end of the 1970's, agriculture was surpassed by oil and gas extraction, reflecting the Nation's response to OPEC's (Organization of Petroleum Exporting Countries) pricing policies. The Federal military and civilian components declined substantially between 1970 and 1980.

Crosshauling goods and services among States and regions can influence the importance of a particular industry. For example, an industry may be exporting beyond a State's boundaries at the same time as its products are being imported from outside the State. If the dollar value of imported goods or services equals or exceeds that produced locally, the industry does not qualify as basic. In other words, the industry is not earning net new dollars from the outside world. It is common for a local industry to produce in excess of local needs while the State must import more of the same to satisfy all its requirements. Such is the case in Oklahoma's forest products industry. Forest products are exported to customers outside Oklahoma, but overall the State is a net importer. Consequently, at the State level the forest products industry does not account for any of Oklahoma's excess employment. We take this to mean that Oklahoma is a net importer of forest products. We shall see later, however, that the forest products industry is a basic industry in two of the State's rural sub-State districts.

Economic base industries	Dependency indicator	
	1970	1980
	(Percent of economic base)	
Oil and gas extraction	18.20	33.53
Agriculture	33.72	27.11
Self-employed	12.50	10.63
Federal military	11.44	7.49
Federal civilian	12.63	4.47
Petroleum refining	3.54	3.22
Machinery, excluding electrical	0	3.17
Air transportation	2.03	1.96
Trucking and warehousing	.68	1.89
Pipeline transportation	1.06	1.31
Subtotal	95.80	94.78
All other industries	4.20	5.22
Total	100.00	100.00

Geographical Importance of the State's Forest Products Industry

Although the forest products industry does not qualify as a basic industry for the State as a whole, this industry is a component of the economic base of two sub-State districts in the southeastern portion of the State (see appendix 2 for a listing of counties by district). Between 1970 and 1980, the forest products industry's importance increased in both areas.

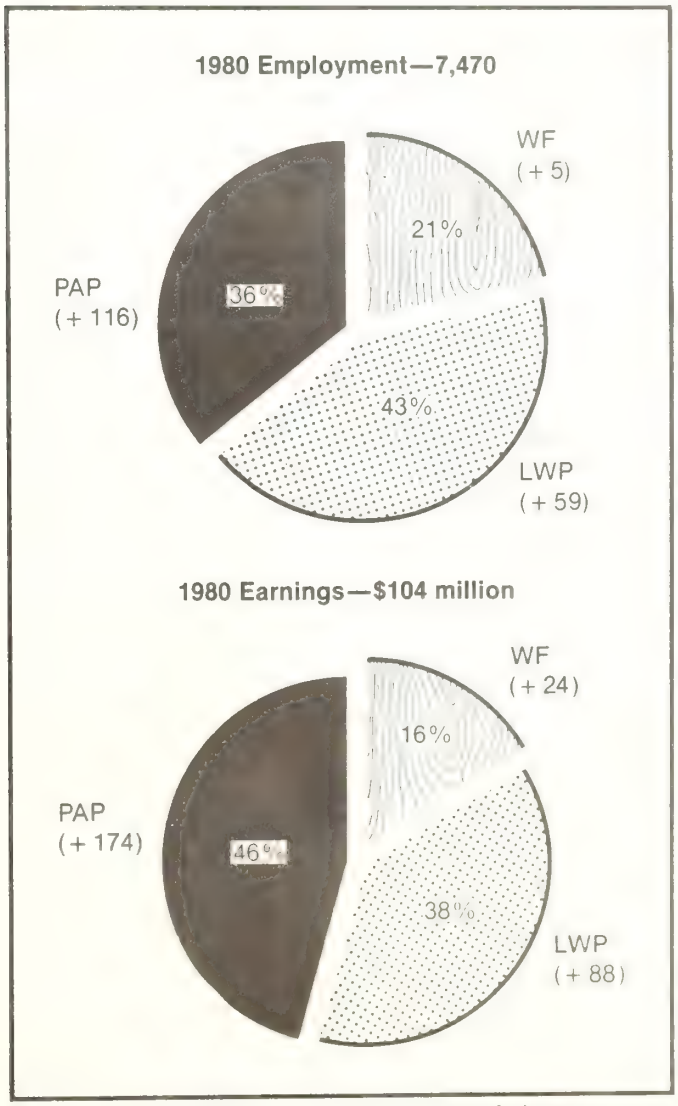


Source: Sub-State estimates for 1970 and 1980 were derived from unpublished county data series provided by the U.S. Department of Commerce, Regional Economic Information System, Washington, DC; and from the Department's *County Business Patterns*.

Composition of the State's Forest Products Industry

Oklahoma's forest products industry is comprised of paper and allied products, lumber and wood products (not including mobile homes), and wood furniture manufacturing. In 1980, lumber and wood products accounted for the largest share of approximately 7,500 workers employed by Oklahoma's forest products industry; however paper and allied products had the largest share of 1980 earnings.

Paper and allied products employment increased substantially during the 1970's. The growth rate for this segment was over five times the average for all industries in the Nation (22.3 percent). The growth rate for lumber and wood products employment was much greater for Oklahoma than across the Nation. Employment in wood furniture, which is the smallest segment of the State's forest products industry, barely changed between 1970 and 1980. During this period, earnings in the State's forest products industry doubled. The largest share of the increase (60 percent) can be attributed to paper and allied products.

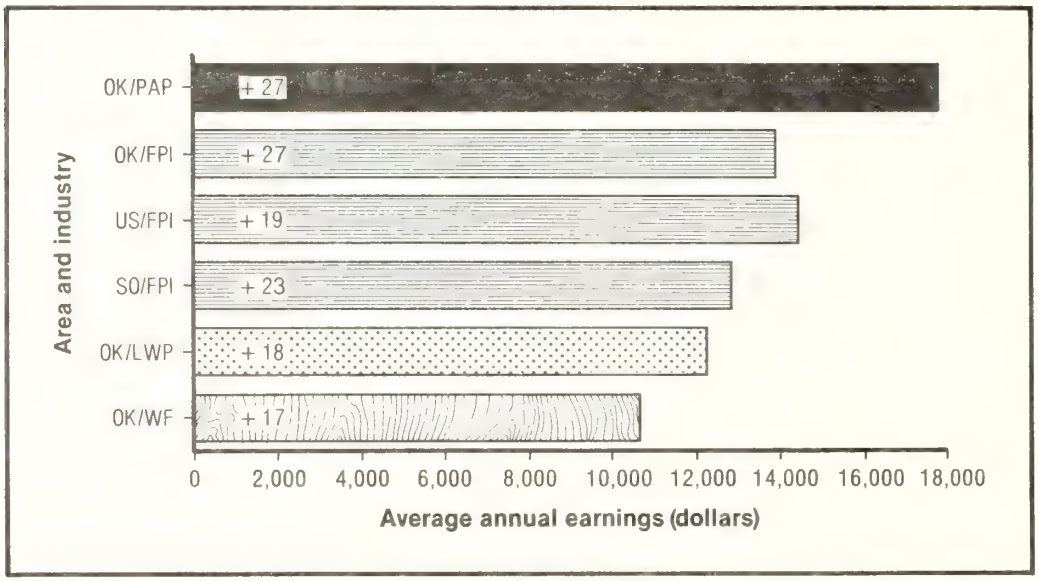


Numbers in parentheses show percentage of change from 1970 to 1980.

Average Annual Earnings per Worker

Average annual 1980 earnings per worker in paper and allied products were greater than were earnings in the other two segments of the forest products industry. Higher average skill levels, capital investment per worker, and unions account for this difference. Earnings in the wood furniture industry were nearly 40 percent less than those for paper and allied products and were significantly below the average for all forest products industries in the South and the United States.

The rate of growth in earnings was greater for Oklahoma's forest products industry than for the South and the Nation. The difference resulted primarily from the growth in earnings of the paper and allied products segment. The rate of change for lumber and wood products and for wood furniture was less than that of the United States and the South.

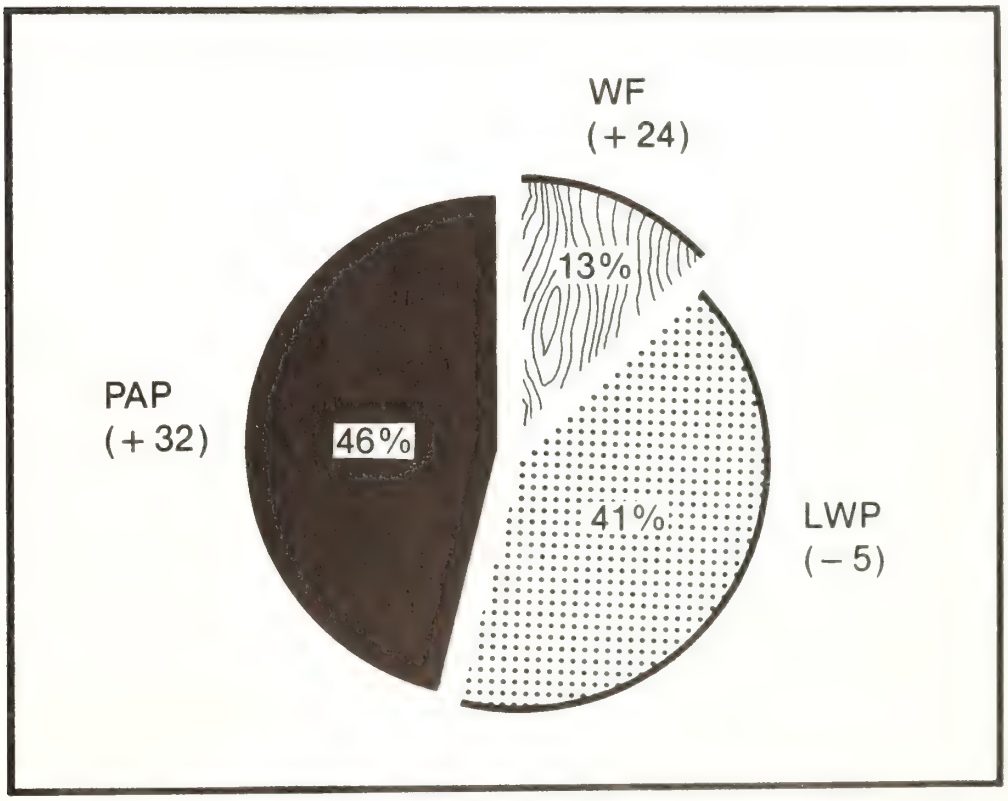


Numbers in bars show percentage of change from 1970 to 1980.

Value Added by the Forest Products Industry

Value added by manufacturing represents income payments made directly to workers and business owners. It is equal to the value of shipments less the cost of materials, parts, supplies, fuel, goods purchased for resale, electric energy, and contract work. Unlike value of shipments, value added includes only the economic contributions of the State's forest products industry. Consequently, value added by manufacturing is considered a better monetary gauge of the relative economic importance of a manufacturing industry than are total shipments.

In 1977, paper and allied products accounted for 46 percent of the $182 million of value added by Oklahoma's forest products industry. Between 1972 and 1977, the value added by paper and allied products increased by nearly one-third, while wood furniture increased by 24 percent. Meanwhile, value added decreased in lumber and wood products.

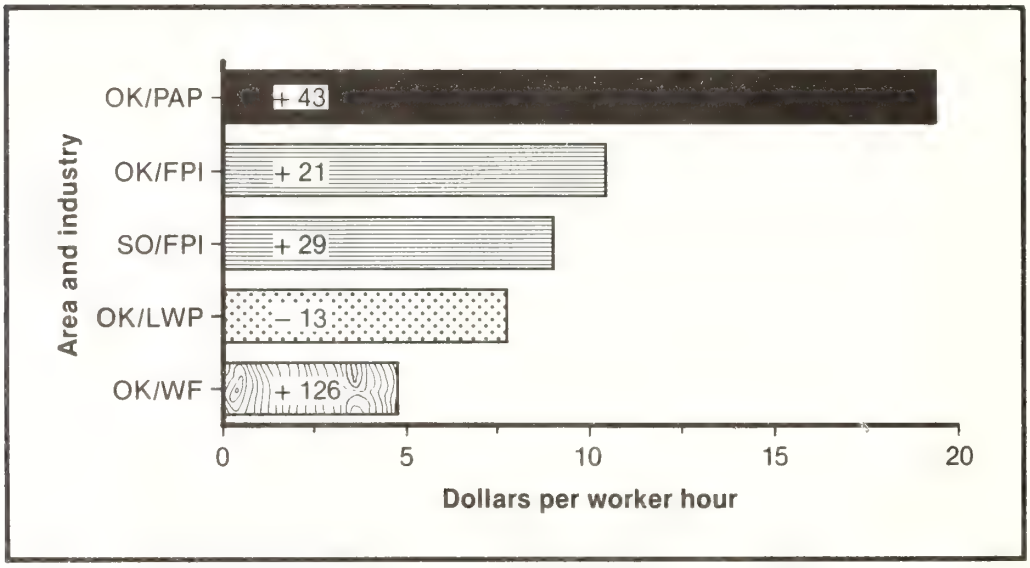


Numbers in parentheses show percentage of change from 1972 to 1977.

Capital Productivity

Increases in productivity are necessary for an industry to remain competitive in the marketplace. Productivity of an industry is measured in terms of value added minus payrolls per worker hour—VAMP (see table 3 for an explanation of how productivity was calculated for Oklahoma's forest products industry). This measure of productivity adjusts for wide differences in payroll among industries and represents profits before taxes.

Not surprisingly, paper and allied products had by far the highest productivity in Oklahoma's forest products industry. Productivity per worker hour was almost twice the average for the State's forest products industry. Paper and allied products is more capital intensive and in the past has attracted considerable investment in new facilities and equipment. During the mid-1970's, this segment exhibited a larger gain in productivity than the average for the South. Oklahoma's wood furniture industry experienced an even larger percentage of gain in productivity; but in absolute terms, this gain was much less than that of the paper and allied products segment.

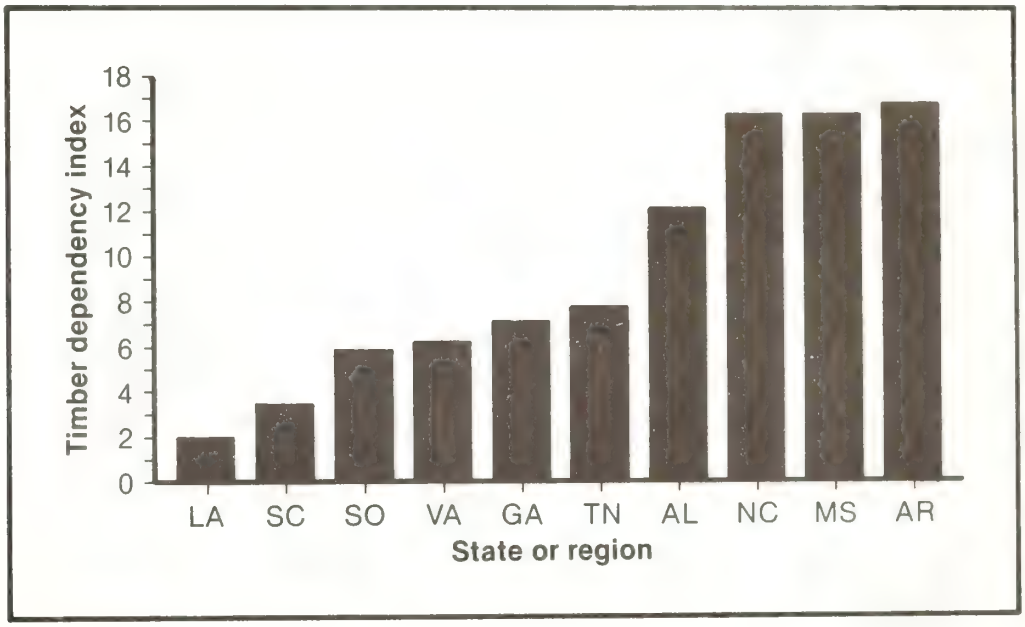


Numbers in bars show percentage of change from 1972 to 1977.

The Forest Products Industry in the South

Importance of the Industry Across the South

The dependency indicators suggest that in 1980 all but four States in the South manufactured forest products in excess of statewide needs. Oklahoma, in addition to Florida, Kentucky, and Texas, was not self-sufficient with respect to forest products; that is, these States imported more forest products than they exported. Consequently, on net balance, their respective forest products industries did not generate new dollars from the outside. In three States—Arkansas, Mississippi, and North Carolina—the forest products industry accounted for approximately one of six basic employees.



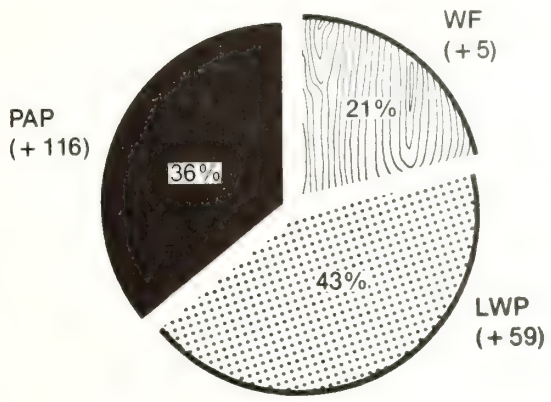
Industry Composition

Lumber and wood products accounted for a slightly larger share of Oklahoma's 1980 forest products industry employment than it did for either the South or the Nation. Although paper and allied products employment was less important in Oklahoma than for the United States, its growth in Oklahoma was much greater than in either the South or the Nation.

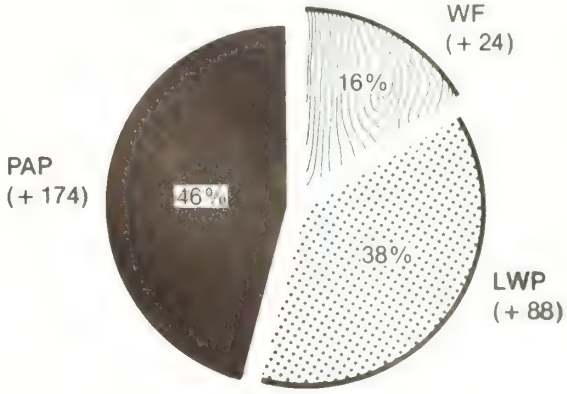
In terms of earnings, the composition of Oklahoma's forest products industry closely resembled that for the United States. But growth in earnings in lumber and wood products and paper and allied products—particularly the latter—was substantially more than for the United States. Wood furniture earnings grew more rapidly in Oklahoma than in either the South or the Nation.

OKLAHOMA

1980 Employment—7,470

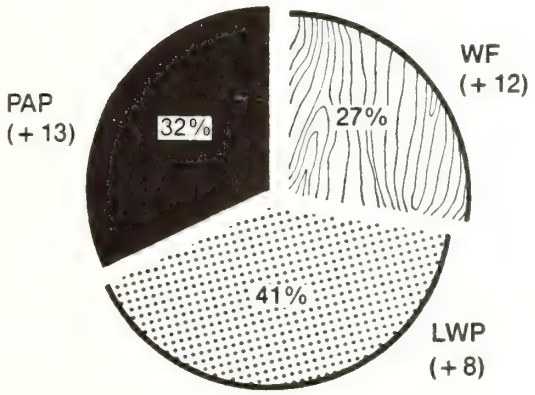


1980 Earnings—$104 million

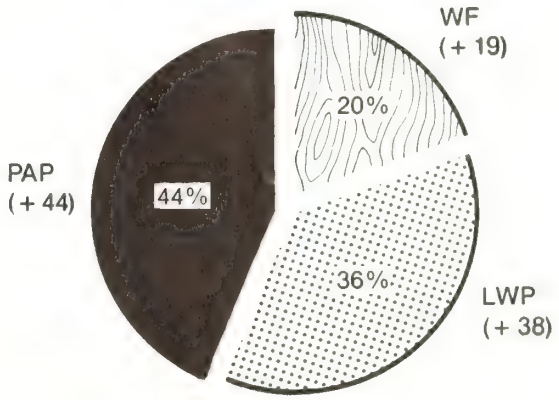


THE SOUTH

1980 Employment—620,567

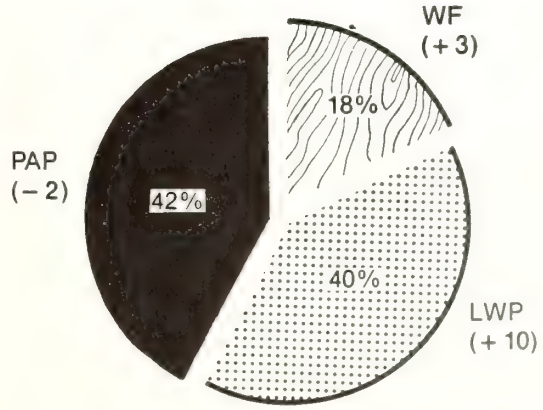


1980 Earnings—$7.96 billion

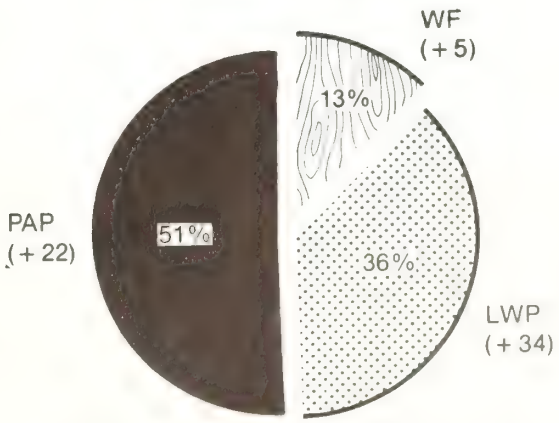


UNITED STATES

1980 Employment—1,634,000



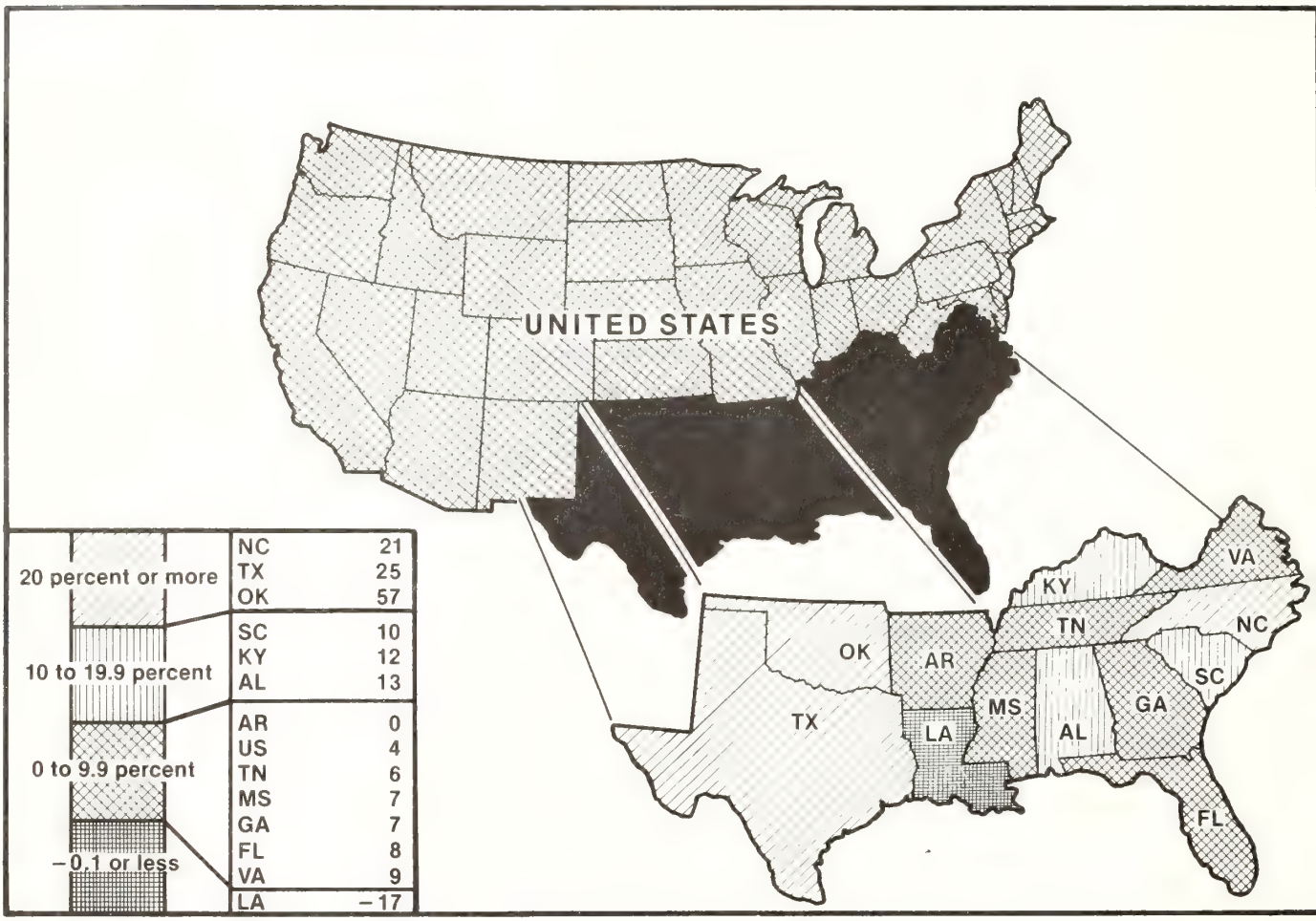
1980 Earnings—$23.65 billion



Numbers in parentheses show percentage of change from 1970 to 1980.

Growth of Employment

With the exceptions of Arkansas and Louisiana, forest products industry employment in each of the Southern States grew faster than did the U.S. counterpart. Between 1970 and 1980, employment in Oklahoma and Texas grew faster than the all-industry average of 22.3 percent. The growth in employment in Oklahoma's forest products industry greatly surpassed the national rate and ranked first among the 13 Southern States.

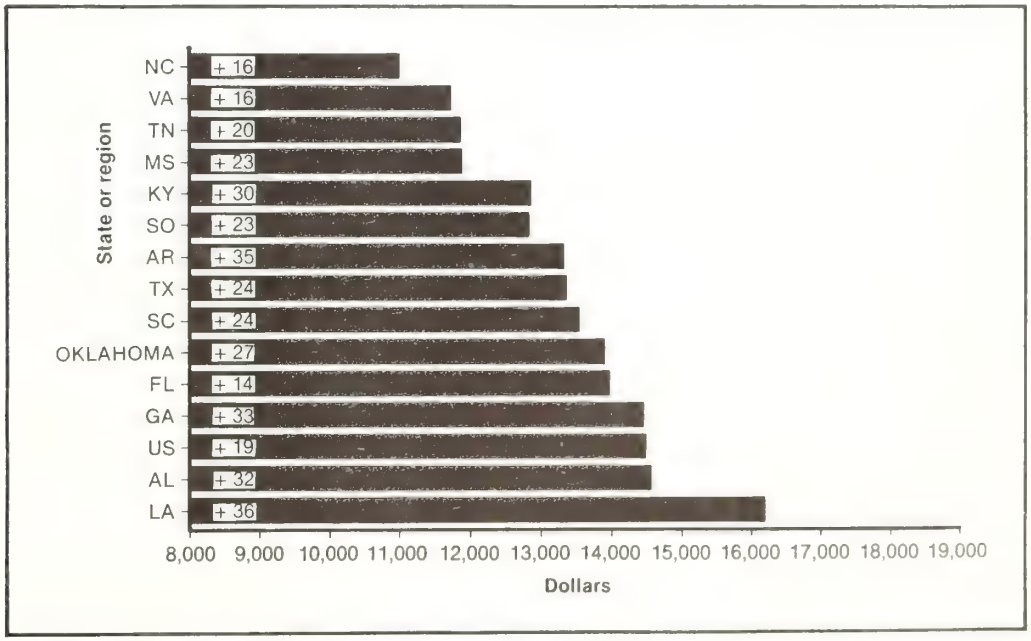


Average Annual Earnings

Average annual earnings per worker in the forest products industry differed significantly by State in 1980: Approximately $5,000 separated the State with the highest (Louisiana) from the State with the lowest (North Carolina). Pulp and allied products manufacturing, which has traditionally paid higher wages than have other segments of the forest products industry, dominated Louisiana's forest products industry. Wood furniture, which has paid lower average wages, dominated North Carolina's industry.

Average annual forest products industry earnings in Oklahoma were greater than for the South, but less than for the United States. Earnings increased faster in Oklahoma than in either the South or the Nation. Among the 13 Southern States it ranked fifth and sixth, respectively, in average earnings in 1980 and in the rate of change between 1970 and 1980.

Generally speaking, paper and allied products dominated the forest products industry in the States with the highest average annual earnings. This relationship reflects higher job skills and unions in pulp and paper manufacturing. Wages, by and large, were the lowest in States where the labor-intensive wood furniture industry was more important.



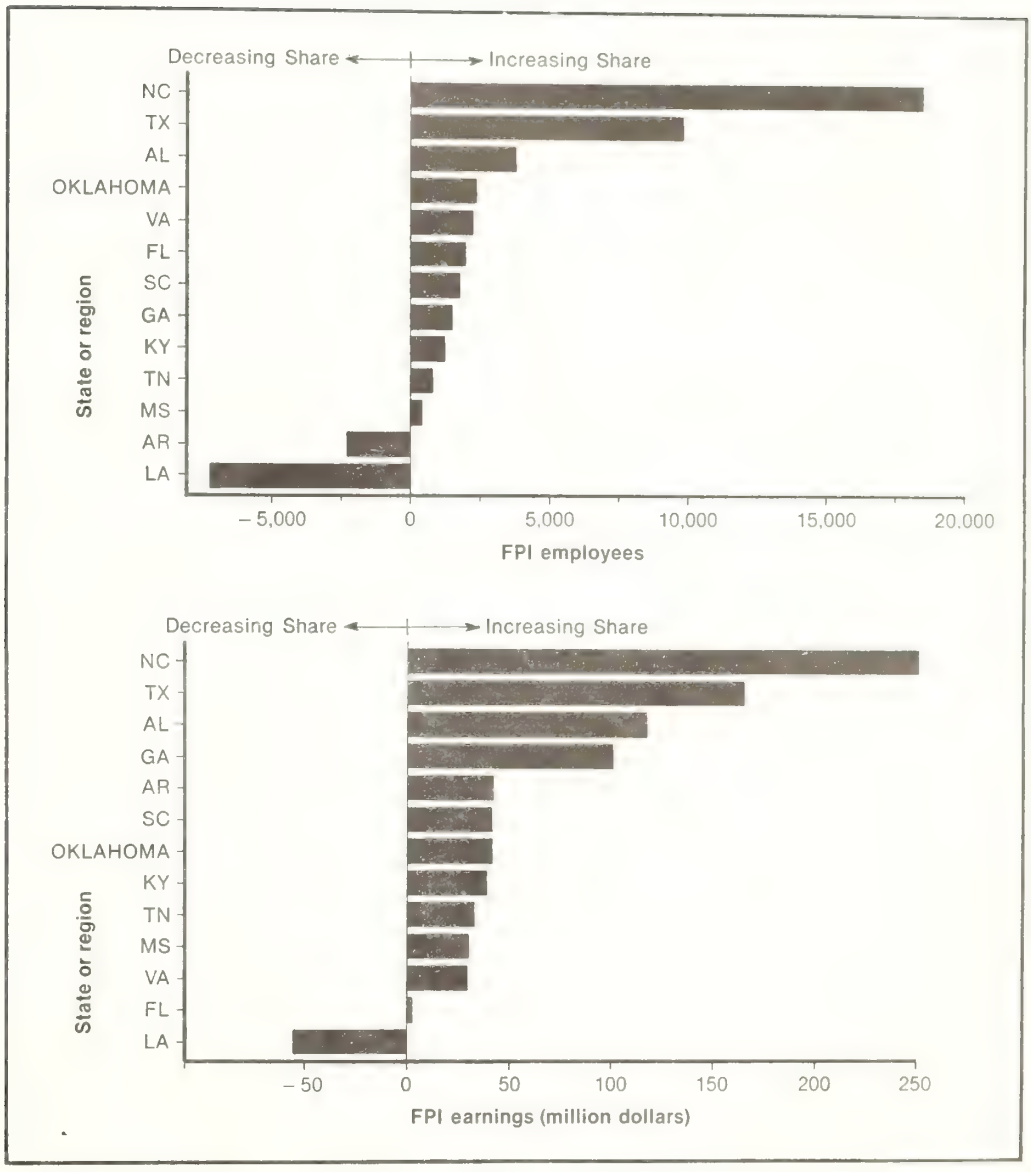
Numbers in bars show percentage of change from 1970 to 1980.

Shift in Employment and Earnings

The regional shift shows how much more or less employment and earnings a State would have had in the forest products industry in 1980 had it grown at the national rate. For example, Oklahoma had approximately 2,500 more employees in 1980 than it would have had if its forest products industry had grown at the national rate.

Between 1970 and 1980, employment in the forest products industry increased in every Southern State except Louisiana and Arkansas. Moreover, all but these two States increased their share of the Nation's forest products industry employment, and all but Louisiana increased their share of earnings.

Increased shares of employment and earnings reflect the comparative advantage the South's forest products industry enjoyed over this industry in the rest of the Nation. Several factors (for example, relatively lower labor costs, lower raw materials costs, and closer proximity to markets) might account for a region's comparative advantage, although adverse trends with respect to one factor need not reduce a region's advantage. In the South, for instance, increasing labor costs need not adversely affect its comparative advantage if increased capital or labor productivity offsets higher labor costs.


Decreasing Share
Increasing Share
NC
TX
AL
OKLAHOMA
VA
FL
SC
GA
KY
TN
MS
AR
LA
State or region
– 5,000
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5,000
10,000
15,000
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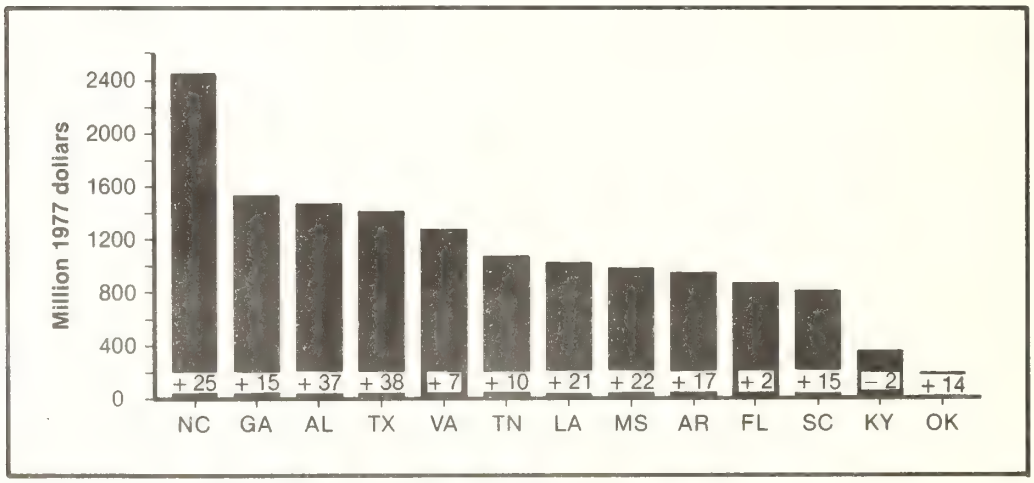
FPI employees
Decreasing Share
Increasing Share
NC
TX
AL
GA
AR
SC
OKLAHOMA
KY
TN
MS
VA
FL
LA
State or region
– 50
0
50
100
150
200
250
FPI earnings (million dollars)

Value Added by the Forest Products Industry

In 1977, the forest products industry of North Carolina produced more value added than any other State in the South. Georgia was second among the 13 Southern States, followed by Alabama. Texas was not only one of the leading States in terms of total value added, it also led the South in terms of the change in value added between 1972 and 1977. Oklahoma was last in terms of total value added. Although the increase in total value added for the forest products industry was rather modest between 1972 and 1977, wood furniture, and paper and allied products experienced substantial gains (24 percent and 32 percent, respectively). One State, Kentucky, produced less value added in 1977 than in 1972.



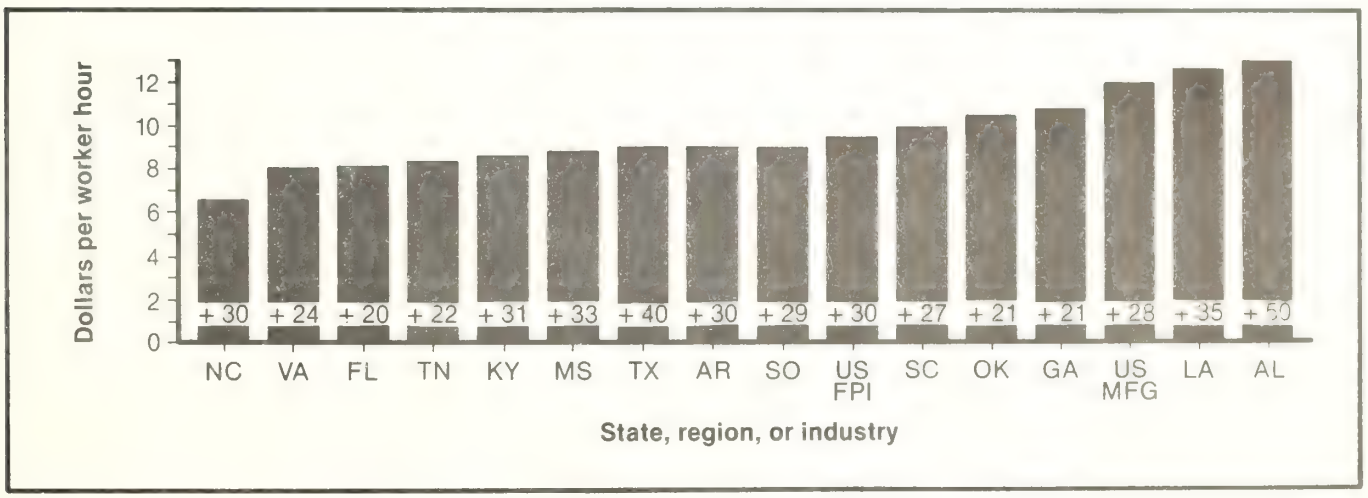
Numbers in bars show percentage of change from 1972 to 1977.

Capital Productivity

Paper and allied products industry, which is more capital-intensive and, therefore, more susceptible to technological change than are other segments of the forest products industry, exhibited the highest productivity within the forest products industry. Wood furniture, on the other hand, is the most labor-intensive of the three. North Carolina, for example, produced more value added than any other State in the South, but the productivity of its forest products industry in 1977 was the lowest. This reflects the dominant role of labor-intensive wood furniture manufacturing in North Carolina.

Increases in productivity exceeded increases in payroll per worker between 1972 and 1977 for all the Southern States. This relationship is in part responsible for the South's comparative advantage in the forest products industry.

In 1977, capital productivity of the forest products industry in Oklahoma was exceeded by only three Southern States. But between 1972 and 1977, the productivity of Oklahoma's forest products industry increased by only 21 percent. This rate of change was lower than for all other Southern States except Florida and Georgia and resulted from sagging profits in the lumber and wood products segment.



Numbers in bars show percentage of change from 1972 to 1977.

Acknowledgment

Many helpful suggestions of several reviewers were incorporated in this research report. This project was funded in part by USDA Forest Service, Resource Program and Assessment Staff, and State and Private Forestry, Area Planning and Development, State Planning for Forest Resources.

Appendix 1
Tables

Table 1—Total labor and proprietorial employment and income, by industry, Oklahoma, 1980[1/]

Industry number	Industry	Employees	Total income
		Number	*Thousand 1977 dollars[2/]*
Wage and salary			
1	Agriculture	17,233	478,448
2	Agricultural services, forestry, and fisheries	5,445	53,890
3	Coal mining	1,608	37,879
4	Oil and gas extraction	68,329	1,422,500
5	Metal mining	76	806
6	Nonmetallic minerals	1,988	27,985
7	Construction	56,585	987,264
8	Food and kindred products	16,421	210,316
9	Tobacco	0	0
10	Textile mill production	1,364	12,290
11	Apparel and other textiles	10,989	78,058
12	Paper and allied products	2,673	47,477
13	Printing and publishing	10,843	125,708
14	Chemical and allied products	3,288	58,814
15	Petroleum refining	8,515	209,477
16	Rubber and miscellaneous plastics	11,790	190,082
17	Leather and leather products	579	4,224
18	Lumber and wood products, excluding mobile homes[3/]	3,213	39,239
19	Mobile homes	370	4,519
20	Wood furniture	1,584	16,815
21	Other furniture and fixtures	623	6,613
22	Stone, clay and glass products	10,778	167,583
23	Primary metals	5,707	99,911
24	Fabricated metals	23,650	352,855
25	Machinery, excluding electrical	38,866	614,782
26	Electrical machinery	13,355	190,974
27	Transportation equipment, excluding motor vehicles	10,131	183,582
28	Motor vehicles	9,659	215,689
29	Ordnance	[3/]—	[3/]—
30	Instruments and related equipment	2,896	39,217
31	Miscellaneous manufacturing	2,492	23,855
32	Railroad transportation	4,388	94,378
33	Trucking and warehousing	20,405	387,318
34	Local transit	1,368	15,067

See footnotes at end of table.

Table 1—Total labor and proprietorial employment and income, by industry, Oklahoma, 1980 [1/] (continued)

Industry number	Industry	Employees	Total income
		Number	*Thousand 1977 dollars [2/]*
Wage and salary			
35	Air transportation	9,607	200,303
36	Pipeline transportation	2,662	53,993
37	Transportation services	1,201	23,911
38	Water transportation	46	847
39	Communications	16,926	309,851
40	Electric, gas, and sanitation services	13,149	245,589
41	Wholesale trade	69,406	1,073,247
42	Retail trade	193,527	1,587,884
43	Banking	19,567	238,119
44	Other credit agencies	10,907	172,954
45	Insurance	15,421	258,390
46	Real estate and combinations	12,251	128,026
47	Hotel and other lodging	9,816	65,911
48	Personal, miscellaneous business, and repair services	42,889	508,745
49	Auto repair service	8,375	126,051
50	Amusement	6,190	41,762
51	Motion pictures	1,590	8,799
52	Private households	21,340	58,880
53	Medical and other health	57,310	780,079
54	Private education	9,452	75,178
55	Nonprofit organizations	36,454	240,003
56	Miscellaneous services	15,560	469,891
57	Federal civilian	47,741	729,579
58	Federal military	46,102	328,392
59	State and local government	188,590	1,681,499
Proprietorial			
60	Farm proprietors	86,025	356,160
61	Nonfarm proprietors	112,172	1,509,808
	Total	1,421,487	17,671,466

[1/] Source of data for this table for Oklahoma, other States of the South, and the United States: unpublished data, U.S. Department of Commerce, Regional Economics Measurements Division, Regional Economic Information System (REIS), Washington, DC, 1982. Unpublished data used by the U.S. Department of Commerce in preparing their *County Business Patterns* (CBP) series on employment and payroll were used to differentiate wood-related from nonwood-related employment and earnings. For example, CBP data were used to separate mobile homes (no. 19) from the lumber and wood products (no. 18) industry. Wood furniture (no. 20) was similarly separated from other furniture and fixtures (no. 21).

[2/] The Personal Consumption Expenditures (PCE) deflator, 1977 = 100, was used to deflate nominal dollars.

[3/] Included with fabricated metals and other related industries.

Table 2—Calculation of 1980 dependency indexes for Oklahoma
(In percent)

Industry	Employment		Oklahoma excess employment [1]	Dependency index [2]
	Oklahoma	United States		
Agriculture	1.40	1.46	—	—
Agricultural services, forestry, and fisheries	.44	.62	—	—
Farm proprietors	7.10	3.03	4.07	27.10
Coal mining	.13	.27	—	—
Oil and gas extraction	5.64	.60	5.04	33.50
Metal mining	.01	.11	—	—
Nonmetallic minerals	.16	.14	.03	.18
Construction	4.59	.74	—	—
Food and kindred products	1.33	1.87	—	—
Tobacco	0	.07	—	—
Textile mill production	.11	.93	—	—
Apparel and other textiles	.89	1.39	—	—
Paper and allied products	.22	.76	—	0
Printing and publishing	.88	1.37	—	—
Chemical and allied products	.27	1.22	—	—
Petroleum refining	.70	.22	.48	3.22
Rubber and miscellaneous plastics	.96	.80	.18	1.18
Leather and leather products	.05	.26	—	—
Lumber and wood products, excluding mobile homes	.26	.71	—	—
Mobile homes	.03	.05	—	—
Wood furniture	.13	.32	—	—
Other furniture and fixtures	.05	.19	—	—
Stone, clay, and glass products	.89	.73	.16	1.06
Primary metals	.46	1.26	—	—
Fabricated metals	1.95	1.77	.18	1.19
Machinery, excluding electrical	3.21	2.73	.48	3.17
Electrical machinery	1.08	2.31	—	—
Transportation equipment, excluding motor vehicles	.82	1.21	—	—
Motor vehicles	.78	.87	—	—
Instruments and related equipment	.23	.77	—	—
Miscellaneous manufacturing	.20	.47	—	—
Railroad transportation	.36	.58	—	—
Trucking and warehousing	1.68	1.40	.28	1.89
Local transit	.11	.29	—	—
Air transportation	.79	.50	.29	1.96
Pipeline transportation	.22	.02	.20	1.31
Transportation services	.10	.22	—	—
Water transportation	0	.23	—	—
Communications	1.37	1.48	—	—
Electrical, gas, and sanitation services	1.09	.90	.18	1.21
Wholesale trade	5.63	5.79	—	—
Retail trade	15.70	16.50	—	—
Banking	1.59	1.72	—	—
Other credit agencies	.88	.99	—	—

See footnotes at end of table.

Table 2—Calculation of 1980 dependency indexes for Oklahoma (continued)
(In percent)

Industry	Employment		Oklahoma excess employment [1/]	Dependency index [2/]
	Oklahoma	United States		
Insurance	1.25	1.89	—	—
Real estate and combinations	.99	1.16	—	—
Hotel and other lodging	.80	1.20	—	—
Personal, miscellaneous business, and repair services	3.48	4.69	—	—
Auto repair service	.69	.63	.06	.41
Amusement	.50	.84	—	—
Motion pictures	.13	.24	—	—
Medical and other health	4.65	5.71	—	—
Private education	.77	1.47	—	—
Nonprofit organizations	2.96	3.01	—	—
Miscellaneous services	1.26	1.63	—	—
Federal civilian	3.94	3.27	.67	4.47
Federal military	3.81	2.68	1.12	7.49
Nonfarm proprietors	9.26	7.66	1.60	10.63
Total [3/]	100.00	100.00	15.02	100.00

[1/] Oklahoma employment minus U.S. employment. Figures may not be exactly equal to Oklahoma minus U.S. because of rounding. Dashes signify no excess employment.

[2/] Individual industry excess employment expressed as a percentage of Oklahoma's total excess employment (sum of column 4).

[3/] Sum of parts may not equal totals because of rounding.

Table 3—Value added, hours worked, payroll, and capital productivity, [1/] Oklahoma forest products industry, 1977 [2/]

Industry	Value added	Payroll	Hours worked	Productivity	Productivity change, 1972-77
	- - *$Million* - -		*Million*	*$VAMP per hour*	*Percent*
Lumber and wood products	74.5	34.2	5.2	7.75	-12.83
Wood furniture	23.0	12.0	2.3	4.78	125.59
Paper and allied products	84.1	26.0	3.0	19.37	43.46

[1/] Productivity equals value added minus payroll (VAMP) divided by hours worked. For a discussion of VAMP, see W. Charles Sawyer and Joseph A. Ziegler. 1980. "The use of VAMP shift as a predictive model." Unpublished paper presented at the annual meeting of the Western Regional Science Association, Monterey, California.

[2/] Source: U.S. Bureau of the Census, Census of Manufactures, for 1972 and 1977, Oklahoma and the United States, available in 1976 and 1980, respectively. In the few instances where data were not available for some subindustry segments, the distribution of the number of establishments was used to estimate nondisclosures.

Appendix 2
Oklahoma Counties by Sub-State Planning and Development Districts

District code	Counties
1	Craig, Delaware, Mayes, Nowata, Ottawa, Rogers, Washington
2	Adair, Cherokee, McIntosh, Muscogee, Okmulgee, Sequoyah, Wagoner
3	Choctaw, Haskell, Latimer, Le Flore, McCurtain, Pittsburg, Pushmataha
4	Atoka, Bryan, Carter, Coal, Garvin, Johnston, Love, Marshall, Murray, Pontotoc
5	Hughes, Lincoln, Okfuskee, Pawnee, Payne, Pottawatomie, Seminole
6	Creek, Osage, Tulsa
7	Alfalfa, Blaine, Garfield, Grant, Kay, Kingfisher, Major, Noble
8	Canadian, Cleveland, Logan, Oklahoma
9	Caddo, Comanche, Cotton, Grady, Jefferson, McClain, Stephens, Tillman
10	Beckham, Custer, Greer, Harmon, Jackson, Kiowa, Roger Mills, Washita
11	Beaver, Cimarron, Dewey, Ellis, Harper, Texas, Woods, Woodward

Maki, Wilbur R.; Schallau, Con H; Foster, Bennett B.; Redmond, Clair H. Oklahoma's forest products industry: performance and contribution to the State's economy, 1970 to 1980. Res. Pap. PNW-363. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

Employment and earnings in Oklahoma's forest products industry, like those of most Southern States, grew significantly between 1970 and 1980. In fact, Oklahoma's share of the Nation's forest products employment and earnings increased during this period. In 1980, lumber and wood products accounted for the largest share of the industry's employment, but paper and allied products had a larger share of the earnings. In 1977, pulp and allied products had higher productivity than either lumber and wood products or wood furniture.

Keywords: Forest products industries, economics (forest products industries), employment (forest products industries), Oklahoma.

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Potential Pacific Rim Demand for Construction-Grade Softwood Logs

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Abstract

Flora, Donald F.; Vlosky, Richard P. Potential Pacific Rim demand for construction-grade softwood logs. Res. Pap. PNW-364. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 29 p.

Markets for small lower grade ("construction-grade"), softwood logs are projected to expand steadily through 1995. Log supplies will lag slightly behind demand until 1990, generating about a 10-percent increase in prices. Prices are expected to be level thereafter. United States exports of construction-grade logs are projected to increase 35 percent by 1990 and another 23 percent by 1995.

Keywords: Markets (external), supply/demand (forest products), trade (Pacific Rim).

Research Summary

"Construction-grade" logs are smaller, lower grade softwood roundwood logs that compete with U.S. number 3 coastal hemlock saw logs. Hemlock logs are 6 to 12 inches in diameter; construction-grade logs range to larger diameters. Projections of demand and supply for construction-grade logs were estimated for 1990 and 1995 for each supplying and consuming country around the Pacific Rim. Principal suppliers are expected to be Canada, Chile, New Zealand, United States, and Union of Soviet Socialist Republics. Expected purchasers are China, Japan, Korea, and Taiwan (a nonparticipant in softwood log trade until the mid-1980's).

Supply equations, estimated for each exporting country, were summed to an aggregate Pacific-wide supply function after adjustments were made for transportation costs, exchange rates, and inflation. A similar process was applied to demand. The aggregate supply and demand functions were then solved for equilibrium price and quantity for 1983—the base year and the last year for which a full complement of data was available. Next, the national equations were projected to 1990 and 1995 by use of shifters such as gross national product and harvest forecasts. Equilibriums were then estimated for those years.

The study produced log flow estimates of 1.72 billion board feet in 1983, 2.2 billion in 1990, and 2.5 billion in 1995. The indicated increases are 35 percent by 1990 and an additional 23 percent by 1995. Log prices, in U.S. dollars and at Pacific coast ports, are expected to increase from an average of $290 per thousand board feet in 1983 to $330 in 1990 and $338 in 1995.

For the United States, construction-grade log exports of 361 million board feet in 1983 were about 15 percent of all softwood log exports from the west coast. The U.S. estimate for 1990 is 488 million board feet; for 1995, 602 million.

These conclusions depend on a stable world economy and the return of exchange rates to about their 1983 levels. The conclusions are independent of inflation rates because they are expressed in real (1983) dollars.

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Introduction

For at least two decades land managers have pondered the fate of timber at the low end of the value spectrum. Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and beetle-killed spruce (*Picea* spp.) in the central Rocky Mountains and the Columbia Basin, defective hemlock (*Tsuga* spp.) in the northern Rocky Mountains, white spruce (*P. glauca* (Moench) Voss) in interior British Columbia and interior Alaska, residual stands of hemlocks (*Tsuga* spp.) and Sitka spruce (*P. sitchensis* (Bong.) Carr.) in southeast Alaska, upper elevation Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) along the eastern slope of the Cascade Range, and "commercial" thinnings in the heart of the Douglas-fir region are all marketing challenges. They have excited interest during high parts of business cycles and despair during recessions.

This report is a country-by-country assessment of demand for such timber and competing supplies that will be offered on all sides of the Pacific Ocean. Demand and supply projections, from which estimates of price and quantities exchanged are taken, were made for 1990 and 1995.

The trees of this study have in common small size, high extraction costs because of poor access and small size, high manufacturing costs because of size, and in some places a significant component with heart rot. This material, which comprises a growing proportion of the timber resource as larger timber is harvested, varies also in ring width and knot size. Removed to the Orient, a portion of this resource is exploited as appearance-grade lumber; the value of that fraction is assumed to be offset by the proportion of small timber that falls into cull and utility grades because of its quality. In the woods, then, the timber evaluated in this study can be seen as clustered at the low ends in size, quality, and accessibility but nonetheless overlapping the large diameter components. For instance, a tree that is economically attractive in size and quality may be in an outlier stand or in a cutting unit's distant corner and thus will not pay its way out of the woods at the time the vicinity is logged. Such timber cannot be characterized precisely because tree grades built around economic worth are not in common use.

At the dock, where log grades can be assigned, the timber in this study is generally No. 3 saw logs, with scaling diameters between 6 and 12 inches and capable of producing at least one-third of the outturn in "standard" lumber grade or better. The study is specifically oriented to logs that are competitive with No. 3 hemlock saw logs from the Coast Range in Washington State. These hemlock saw logs, with relatively wider rings generated by productive sites, are called "coast grade" in the trade in Japan and elsewhere, contrasting with tighter grained "Cascade" (U.S.) logs. These "J-sort, coast" logs, exported primarily for general construction and structural uses not based on appearance, provide the benchmark values used in this study. Considered roughly comparable in value are the "K-sort" logs destined for Korea, typically woodsrun and averaging 9 inches or less in diameter. Also discussed are British Columbia No. 4 logs between 4 and 14 inches in diameter. Together, these lower value logs are called here "construction-grade" to distinguish them from larger, more valuable "structural-grade" logs that compete with U.S. No. 2 saw logs. Both strata are arbitrary, as more than 60 log grading assortments are recognized at the port of Grays Harbor alone.

Construction-grade logs from North America are expected to compete with radiata pine (*Pinus radiata* D. Don, also called Monterey and Insignis pine) from Chile and New Zealand, and all but the largest of Soviet softwood logs from eastern Siberia and the Soviet Union Far East, especially larch (*Larix* spp.). Construction-grade softwood logs embrace 35 percent of all softwood roundwood and sawn wood traded around the Pacific and 80 percent of all softwood log trade in that region.

The next section describes in general how log prices and overseas flows were projected for construction-grade logs. In the subsequent section is a discussion of economic conditions in each country that affect its timber supply or demand. Also explained are the assumptions made for each country. Too, the supply or demand outlook for each nation is portrayed graphically.

Composite results for the Pacific Rim, which determine estimated Rim-wide log prices and flows, are shown and discussed in the last section. The appendix contains the economic detail for each country.

How the Projections Were Made

For each Pacific Rim country involved in log trade, a supply curve or a demand curve (or both) was estimated, generally by econometric methods. Putting log trade and prices into a supply-demand framework has the advantage of dealing explicitly with the relationships between price and quantity. It also provides a common conceptual framework for dealing with the many diverse economies around the Pacific. The approach used in this study has not been applied previously to international forest products trade among several countries.

From historic data a demand equation, relating the volume of logs imported to their price and other factors that change over time, was developed for each consuming country. A typical equation related the volume of log imports to their unit value as they entered the country. A demand equation is plotted in figure 1, with values of all independent variables except price set to levels appropriate to 1983. Thus figure 1 shows the interaction of value and volume with all factors that could affect their relationship at 1983 levels.

Supply equations that relate the volume of logs exported to price and other factors were estimated individually, in a similar manner, for each sender country. The supply curve of figure 1 shows that in 1983 higher prices would have induced greater exports.

Demand calculations were made for China, Japan, Korea, and Taiwan. Supply estimates were developed for Canada, Chile, New Zealand, United States, and the Soviet Union.

Price and quantity data in the study are annual averages. Results should be interpreted similarly, with prices seen as averages of values that fluctuate seasonally, as do quantities. Calculations are done in local currencies and cubic meters.

Inflation has been great in several of the countries studied. For a comparable dimension prices were adjusted to 1983 "real" levels for each country before analyses were begun; generally, wholesale price indexes were used.

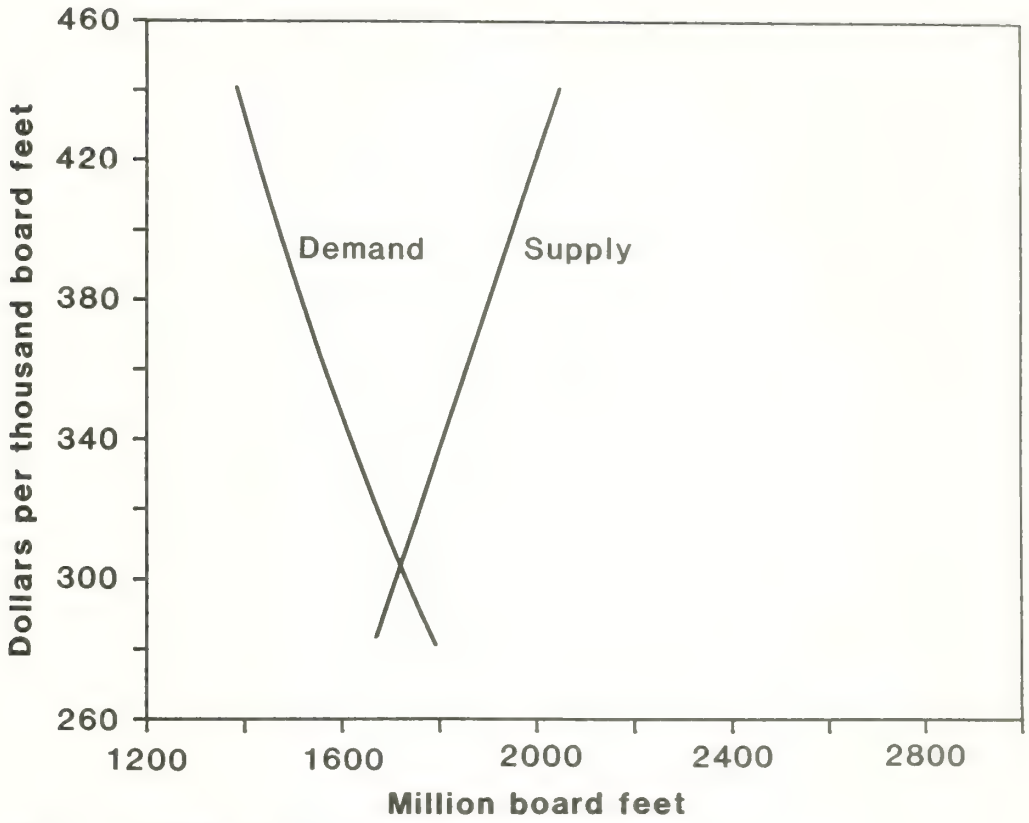

Figure 1.—Total Pacific Rim supply and demand for construction-grade logs, 1983.

Each supply and demand equation includes other variables that shift the curves with the passage of time. The most commonly used "shifter" is GNP (gross national product) in demand equations. Supply equations use timber production and domestic consumption. Shifting variables that lend themselves to forecasting and World Bank (1984) projections of GNP were used. Reports of national forestry agencies and consultants were used for timber yield and consumption figures, which were used in certain supply and demand equations.

After supply and demand equations were developed, they were summed to yield an aggregate supply function and an aggregate demand function for the Pacific Rim. For this step it was necessary to convert values to a common currency relevant to the United States. Demand and supply equations were converted to U.S. dollars from 1983 exchange rates.

Demand equations were further adjusted for freight charges from supply countries. This step was especially important because consuming countries are different distances from source nations. Thus the demand of each country, initially expressed in c.i.f. (cost, insurance, and freight) terms, was recast in f.a.s. (free alongside ship) values along the west coast.

A similar adjustment was made for supply relations. The initial equations pertained to exports f.a.s. at the sending country. To be compatible with c.i.f. demand functions at the receiving country, the f.a.s. supply prices must be raised to include shipping costs to the demand country. Next, to be compatible with the demand functions, which were adjusted downward to relate to dockside supply prices in the United States, the supply functions must also be adjusted downward. This double adjustment process, wherever it was appropriate, was consolidated into a single step and thereby brought competitors' prices to America's door.

With all the demand and supply functions in a U.S.-compatible price context, they were summed horizontally. At each of a number of price levels the quantities estimated for 1983 for the demand countries were added together and plotted, yielding the consolidated demand function of figure 1. Identically, supply relations were summed. Their amalgamation appears also in figure 1. The point of crossing, at about 1.75 billion board feet and $300/MBF (thousand board feet), coincides with the actual Pacific Rim market for construction-grade logs in 1983.

The triangular area below the intersection, between the supply and demand curves, is of special interest. At each price level in that zone, the horizontal distance between the two curves measures "excess demand." That is the additional volume of timber, beyond what was offered at those prices, that would have been absorbed by Pacific Rim markets. Had any supplier been able to provide logs at dockside at those prices, the presumption is that they would have been sold. The analysis shows that an opportunity existed for lower cost logs in that triangle.

Projections of demand and supply to 1990 and 1995 for each country were made by inserting in the equations values for GNP and other shifting variables appropriate to those years. As with 1983, demand and supply estimates were then summed, producing the Pacific Rim market supply and demand curves of figures 2 and 3.

Assumptions that are key to this set of projections and all other forecasts in the study are that the world economy will not experience either a sharp recovery nor significant recession within the coming decade, so that markets for products offered by export-dependent countries like Japan will continue to grow modestly. It is also assumed that interest rates will decline enough to encourage capital formation at its 1983 level but will not fall so low as to discourage saving at less than the 1983 rate. These assumptions are considered not very demanding and to have a high probability of achievement.

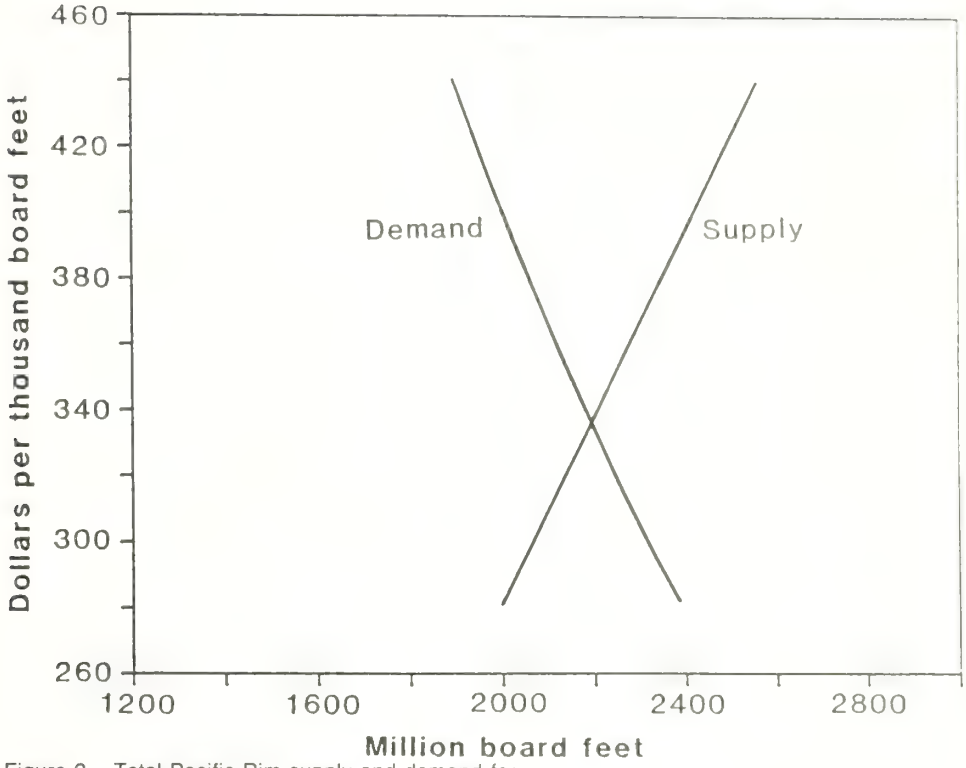

Figure 2.—Total Pacific Rim supply and demand for construction-grade logs, 1990.

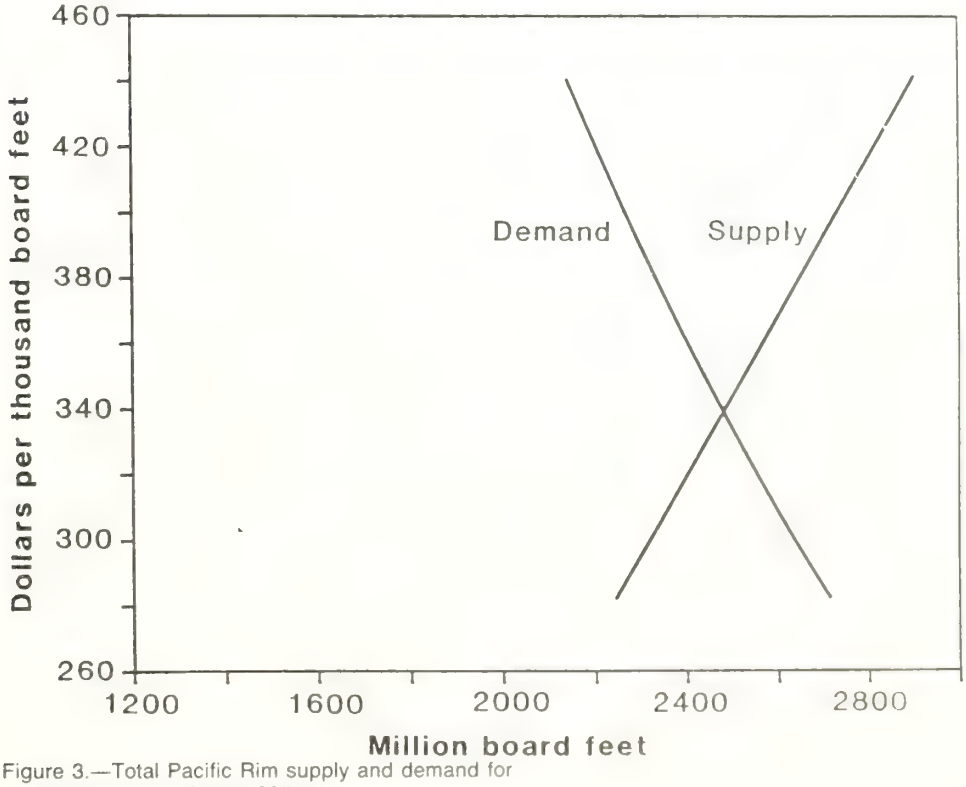

Figure 3.—Total Pacific Rim supply and demand for construction-grade logs, 1995.

The Country Studies

In this section are described demand and supply estimates for individual countries, combined into the composite demand and supply curves of figures 1 to 3. Here the underlying reasoning and assumptions are laid out, and the supply and demand curves for each country are shown. The supporting mathematics is described in the appendix.

Japan

Japan imports almost half the softwood construction-grade logs that move across the Pacific Ocean. Japan's proportional share of the market has declined, primarily because of China's entry. Starting in the early 1960's, Japan's roundwood imports climbed steadily through the 1970's. That growth reflected rising housing starts and an ever stronger economy (Darr and Lindell 1982). During the 1978-83 recession gross national product continued to grow but at a slower rate. From 1970 to 1978 the inflation-adjusted rate of GNP growth was about 5 percent; from 1979 to 1983 it was about 4 percent. Housing starts, having reached about 2 million in 1973, were about 1.5 million per year for the balance of the decade, dropping to about 1.1 million during the recession.

The affluence of Japan is well known. Gross national product per capita was about $10,000 in 1982, having risen an average rate of 6.1 percent per year since 1960 (World Bank 1984). Comparable figures for the United States are $13,000 and a 2.2-percent growth rate. Moderation of the Japan economy is seen in its inflation rate. Consumer prices are rising at about 2.5 percent per year, compared with about 11 percent during the growth and energy constraints of the 1970's.

Japan is highly dependent on imports. Imports, however, are equivalent to only about 12 percent of GNP, a rather small figure for an insular economy, and one that reflects emphasizing imports of raw materials rather than finished goods. United States imports are about 8 percent of GNP. For Japan, exports equal about 13 percent of GNP; for the United States, about 7 percent.

For Japan, softwood roundwood of all kinds, including pulpwood and appearance-grade as well as construction-grade logs, comprise about 2.5 percent of total imports (Katsuhisa 1984). Japanese interest in improved self-sufficiency in wood products is well known (see, for example, Japan Forestry Agency 1984). Log and lumber imports, including hardwoods, were about 20 billion board feet in 1982, whereas domestic log production has been fairly stable at about 7 billion board feet since 1977. Almost half the plantations in Japan are 16 to 35 years old, many ready for commercial thinnings. About 60 percent of the domestic forests are softwoods. Japanese economists (for example, Nomura 1984) believe that domestic supplies will not materially reduce their demand for construction-grade logs before 1995, mainly because cultural treatments have lagged and extraction costs are high.

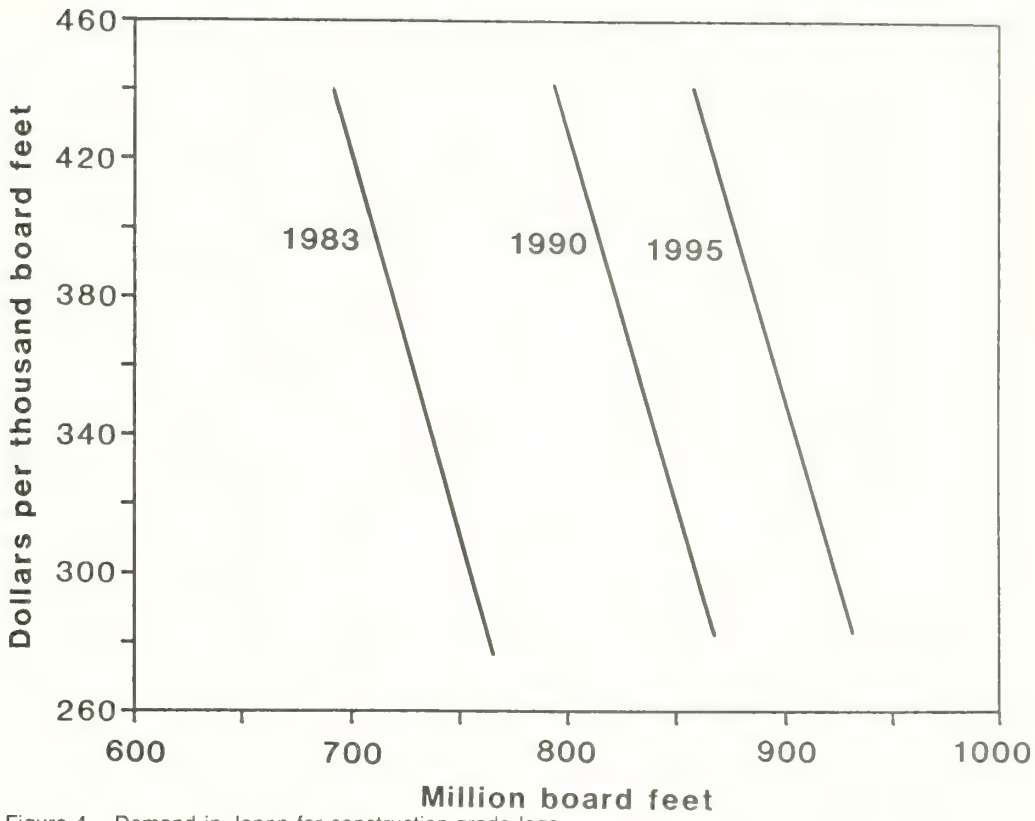

Figure 4.—Demand in Japan for construction-grade logs.

Because of Japanese emphasis on imports of appearance-grade logs, and because grades and sizes of logs are not separated in import statistics, for this study it was necessary to estimate the volume of construction-grade logs arriving in Japan from each supplier country. Proportions were based on a study on wood usage in 1981 (Japan Forestry Agency 1983). Overall, about 35 percent of the imported logs used for lumber become boards, boxes, packing, furniture, cabinets, and other products. This value does not depend on surface appearance nor on stress rating. Reported values of imported logs were similarly adjusted. The effect of this adjustment was to bring the 1983 c.i.f. value of imported construction-grade softwood logs to an average of $430/MBF. A considerable variation among sizes and species was recognized in the study.

Figure 4 portrays the estimated demand for construction-grade softwood logs in Japan, f.a.s. the U.S. west coast. The curves show the volume that would have been purchased at various prices in 1983, with projections to 1990 and 1995. The curves represent Japanese demand for wood from all sources, adjusted pricewise to include transportation and related costs. For example, a demand price of $430/MBF in Japan corresponds to a demand price in the United States of about $300/MBF.

The shift of the curves to the right over time was estimated on the basis of continued growth in GNP at an inflation-adjusted rate of at least 3 percent, which supports housing starts at rates adjusted from Ueda and Darr (1980). The estimates are 1.3 million residences in 1985, 1.4 million in 1990, and 1.3 million in 1995; the decline in the 1990's is attributable to demographic factors.

Republic of Korea

In 1982 Korea consumed about 18 percent of the construction-grade softwood logs traded in the Pacific Basin. Rapid economic growth spanning two decades suggests that Korea will be a steadily growing force in the timber trade. Population there is about 40 million, and gross national product per capita is about $1,800. The average annual growth rate per person for economic welfare has been about 7 percent, in real terms, since 1960. (For the United States the comparable figure is 2.3 percent.) With almost no natural resources, Korea has changed in 20 years "from a marginally subsistent agricultural economy into one of Asia's major industrial nations" (U.S. Department of Commerce, International Trade Administration 1983). The nation's commitment to economic growth is frequently stated, and its strong support of industry is clear. Materials demand from the industrial sector has contributed to the inflation rate in Korea, which increased about 20 percent from 1960 to 1980. Over the same period real GNP grew about 10 percent per year. The recession reduced the country's inflation rate and its GNP growth rate to about 3 percent per year. The Korea Development Institute (quoted in IBR, Inc. 1984), however, expects inflation to remain below 3 percent while the GNP growth rate rises to 8 percent, at least through 1985.

As in Japan, manufactured exports have been a primary driver of the economy in Korea. Korea is well known for its turnkey development of major industrial and energy facilities in other countries. These activities are supported by imports equivalent to about 37 percent of gross national product.

Korea has a significant external debt problem. In 1982 external public debt was equal to about 28 percent of GNP (World Bank 1984). On the other hand, gross domestic saving is equal to almost one-fourth of GNP.

Of its $24 billion of imports in 1982, about 0.5 percent was spent on softwood lumber and logs (World Bank 1984; United Nations, FAO 1984). To the Pacific Northwest, Korea is an important client for logs; "K-sort" is standard timber trade jargon for small logs meeting Korea's specifications. Korea's conifer log imports in 1983 were about 400 million board feet.

For a decade, Korean log imports have shown a strong relationship to their gross domestic product (GDP), an economic measure that is similar to gross national product. This relationship was used to shift the demand curve through time. Figure 5 shows estimated demand curves for Korea.

Two potential sources of change are not reflected in this study. One is Korea's program of reforestation, whose production so far has moved into pulpwood, mine timbers, and fuel wood. During the 1970's about 1 million hectares were planted in hardwoods and softwoods. In 1984 the Korean Office of Forestry began a policy of restraining the harvest of pine trees to stands older than 50 years, with similar age limits on other species. This regulation, considering the age structure of Korea forests, appears to postpone any increase in domestic harvest.

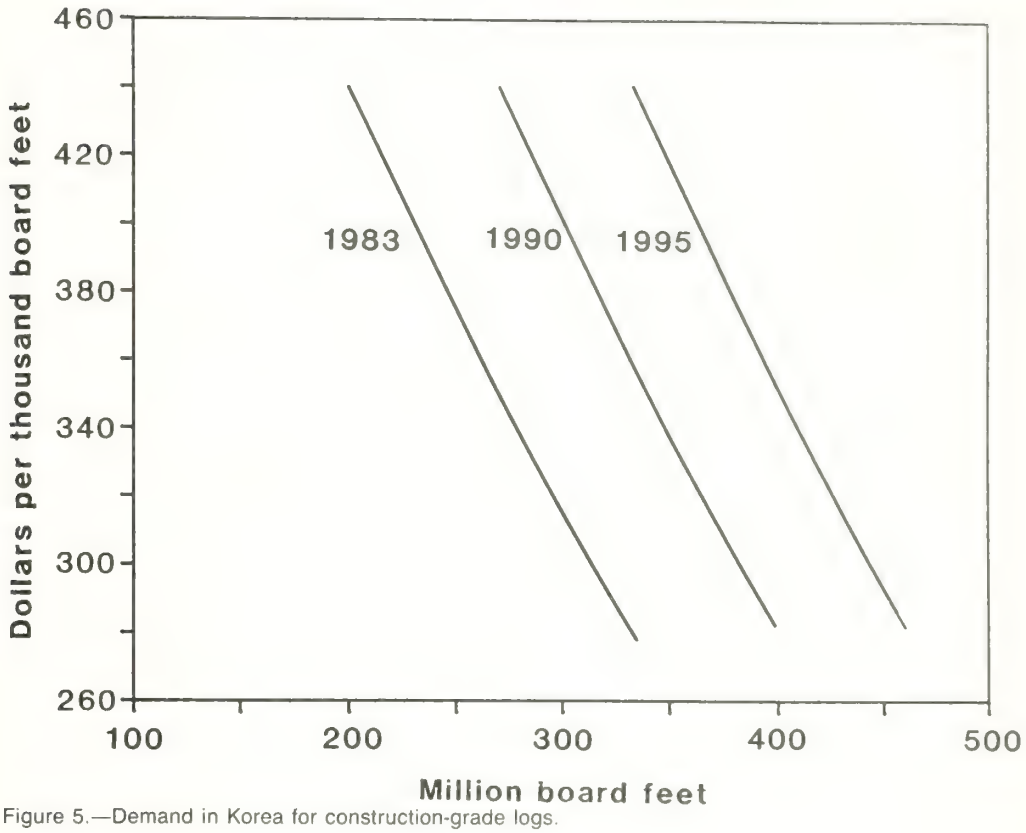

Figure 5.—Demand in Korea for construction-grade logs.

The second element of uncertainty pertains to the 5-year plan that increases emphasis on social development, including housing. The plan, effective in 1982, calls for tripling the rate of home construction from about 100,000 to about 300,000 units per year. The effect on wood use may be small, however, because less than 2 percent of homes are built from wood; most are masonry.

Taiwan (Republic of China)

Taiwan, with a population less than half that of Korea, has a GNP that is about 70 percent of Korea's. Per capita income is about $2,600 (U.S. dollars), about 45 percent higher than Korea's. Industrial development in Taiwan has followed a similar path, with growth rates of about 10 percent per year in GNP from 1960 to 1980 (U.S. Department of Commerce, International Trade Administration 1983). During the recession the growth rate dropped to about 4 percent (Economic Daily News 1984). The real growth rate of GNP is expected to have returned to 6 percent in 1984 (World Bank 1985).

With limited natural resources, Taiwan is attentive to foreign trade. Exports account for about half of the GNP. Wood products, primarily hardwood plywood, are associated with 6 percent of Taiwan's exports and about 4 percent of its manufacturing workers (BIS Marketing Research Limited 1982). Until 1981 Taiwan was the world's largest plywood exporter. First place has lately been taken by Indonesia (U.S. Department of Agriculture, Foreign Agricultural Service 1983b). Taiwan has relied for at least two decades on hardwood logs from Asia to produce (for export) veneers, hardwood plywood, and "value-added" plywoods such as overlays and hard finishes.

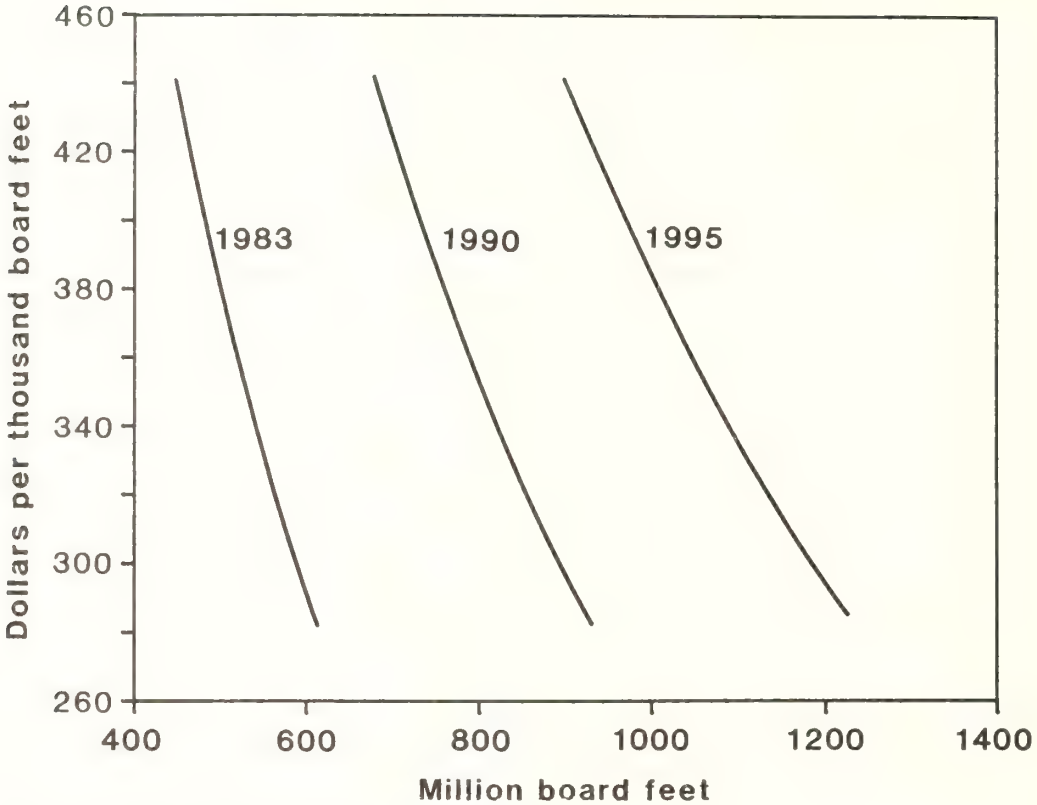

Figure 6.—Demand in China for construction-grade logs.

For its domestic construction needs, Taiwan has relied on its own forests. About half the country is in timber, of which about one-fifth is conifers. Harvests have declined steadily since about 1970, however (Taiwan government statistics cited in U.S. Department of Agriculture, Foreign Agricultural Service 1983b). Conifer log production has dropped by almost half since 1971 along a steady linear trend (Jen 1982, 1984). In the same period housing starts increased sixfold, pressing softwood prices upward. Adjusted for inflation, log prices doubled in a decade.

Taiwan softwood imports have been limited to pulp chips and pulp almost exclusively. Pacific Rim softwood demand projections seem to require, however, that provision be made for potential demand for construction wood as domestic softwood supplies decline. To this end demand curves were estimated for softwood consumption from all sources, and supply curves for domestic softwood log production. Net demand is shown in figure 6. The negative portion of the horizontal axis indicates that in 1983 Taiwan would have been a net supplier at high prices. The shift of demand over time was based on its relationship with GNP. Supply is assumed to shift along its linear track at the rate experienced in the 1970's.

People's Republic of China

With perhaps 2 million cottage industries, a vast rural area, and the prevalence of barter and exchange of services that small farming implies, the published estimates that put GNP per capita in China between $300 and $400 are undoubtedly inadequate estimates of economic welfare. The economic significance of foreign trade to China is similarly hard to gauge because of an administered floating exchange rate, administered domestic prices that mask inflation, and an internal pricing structure that restrains imports, subsidizes investment with a zero-percent interest rate, and keeps certain urban consumer prices (including rent and grain) relatively low (Lardy 1983; U.S. Department of Commerce, International Trade Administration 1983). Creation of free enterprise zones and the 1984 plan to loosen the economy will have as-yet-unpredicted effects on economic activity. Finally, the short recent history of active economic development makes econometric demand estimates, based on historical evidence, impossible.

Since 1977 China's trade has doubled every 3 years. Although China has lately enjoyed a foreign exchange surplus it is less than $25 billion, and total exports in 1984 were about $43 billion. Although this activity is trivial relative to that in the United States, China's exports are equivalent to more than 10 percent of published GNP. This compares with about 20 percent in the United States and is considered remarkable in the context of China's history of economic independence. For economic development and trade expansion, China is dependent on a mixture of foreign investment and borrowing from banks, foreign countries, and world organizations. Clearly pursuing these various avenues cautiously, China must meanwhile ration its foreign exchange among the many raw materials and capital goods in which the country has shown interest.

It is assumed for this study that China will allocate a constant fraction of its spending on imports to softwood logs. In 1983 this was about 1.3 percent. It follows from this assumption that at higher prices the Chinese will purchase less timber (fig. 7).

It is also assumed that imports will remain at about 9 percent of national income. World Bank (1984) projections were used to support an estimate that the national income in China will rise 8 percent per year through 1985 and 6 percent per year thereafter.

China is estimated to have imported about two-thirds of a billion board feet of construction-grade logs in 1983. The comparable estimate for Japan is about 1 billion board feet. These volumes represent for China about 75 percent of all log imports, whereas for Japan construction-grades are estimated to constitute about 35 percent of log imports.

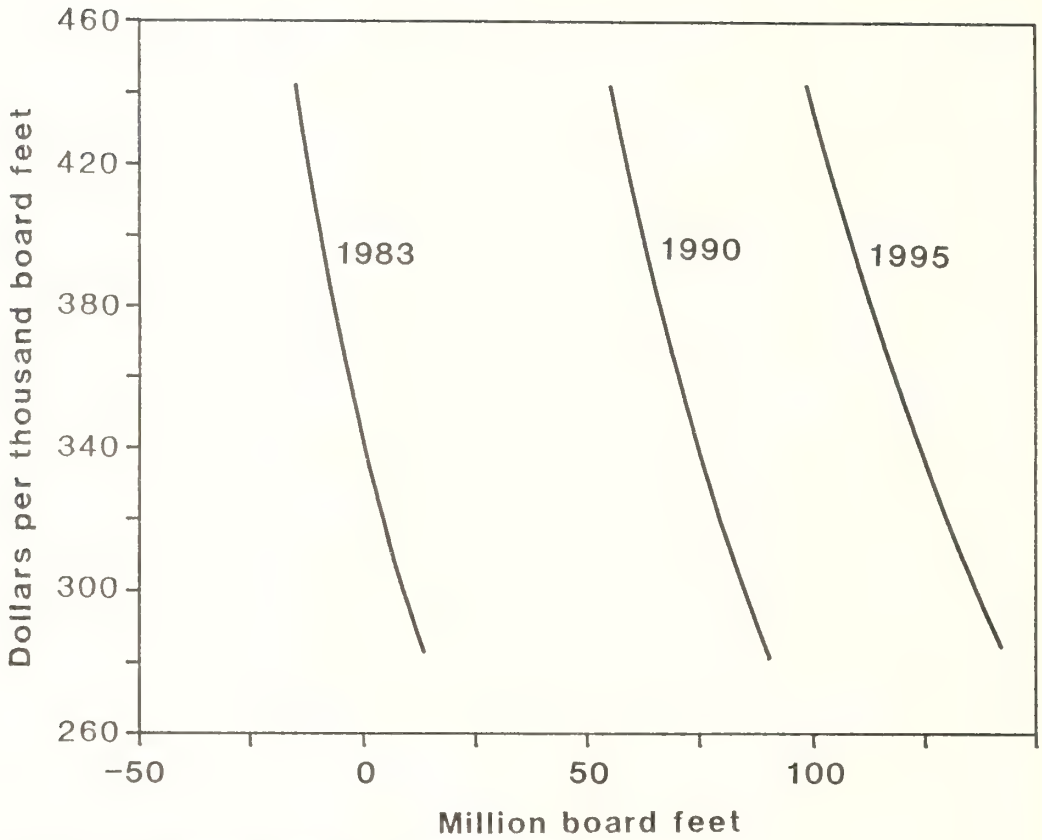

Figure 7.—Net demand in Taiwan for construction-grade logs. Negative quantities represent exports from Taiwan to non-Taiwan countries; positive quantities represent imports to Taiwan.

Supply Estimates

United States

Log export data for the United States from 1963 on was used to estimate the shape of the supply curve for construction logs (fig. 8). In 1983 U.S. exports of construction-grade softwood logs were about 425 million board feet, about 15 percent of all log exports. Their average dockside value was about $290/MBF.

Shifts in the supply curve over time are keyed partly to harvest volumes in the Douglas-fir region as projected by Haynes and Adams (n.d.) for a national report on timber supplies (USDA Foreign Agricultural Service 1984). The regional harvest estimates integrate economic supply and demand forces that arise from the several U.S. supply and demand regions and impinge on log supplies available for export. Figure 8, therefore, indicates declining sales from the United States.

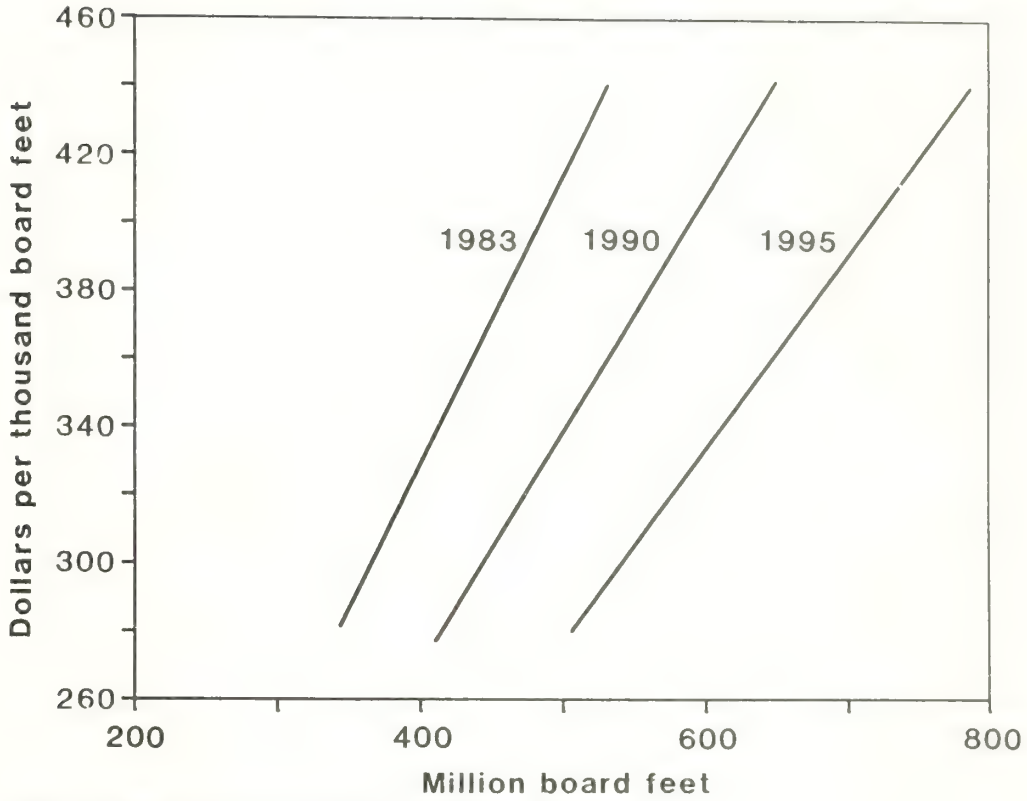

Figure 8.—Supply of construction-grade logs exported from the United States.

Soviet Union

As with China, an administered nonconvertible currency creates difficulty in gauging the scale of economic activity in the U.S.S.R. For several reasons, the Soviet measure of "net material product" is not comparable with the same measure for other countries (The Economist Intelligence Unit 1984c). A comparison of these measures over time, however, suggests that during the 1978-83 recession the Soviet economy grew between 3 and 4 percent per year in real terms, with a rate of 3 percent estimated for 1984.[1/]

Trade circumstances in the U.S.S.R. are more clear, although many Soviet transactions with eastern bloc countries are not at prevailing world prices (The Economist Intelligence Unit 1984c). In 1982 their exports were about $120 billion; in that year U.S. exports were about $210 billion. Oil and natural gas account for three-fourths of the U.S.S.R. export earnings from the West, a degree of dependence that has contributed to their trade deficit. During the 1980's period of low oil and gas prices the U.S.S.R. is increasing its oil exports. Conversely, the U.S.S.R. has benefited considerably from oil sales during strong portions of world economic cycles. There presently (1985) exists no agreement among analysts about whether Soviet oil exports can continue at their early 1980's level. A moderate upward trend in petroleum exports to the West apparently has been at the expense of sales to eastern Europe and domestic consumption (The Economist Intelligence Unit 1983). In any case, Soviet commitment to exports of oil, gas, and coal is clear.

[1/]International Monetary Fund. International financial statistics. Data tapes on file, DATABNK. Seattle, WA: University of Washington; 1984.

Only about 4 percent of Soviet log production, including hardwoods, is exported; however, this material generates about 3 percent of U.S.S.R. export earnings (USDA Foreign Agricultural Service 1984). That level is comparable to the role of timber in U.S. exports. There is an increasing emphasis on timber harvests in Siberia and the Far East, which now account for more than 40 percent of the Soviet timber production. The eastward shift has occurred primarily because of past heavy inroads on the timber resource of European Russia. Exports from eastern U.S.S.R. are important not only to that country but also to Pacific Basin wood products trade. Logs appear to constitute virtually all of this flow, a circumstance that will change as pulping and sawing plants are established along the route of the new Baikal-Amur railroad from southern Siberia to the sea (United Nations, Economic Commission for Europe and FAO 1980). Logs exported from eastern U.S.S.R. constitute almost 60 percent of the construction-grade logs sold by Pacific Rim countries. This figure includes shipments by rail from U.S.S.R. to China.

The Soviet timber industry, operating in a centrally planned economy, is provided with 1- and 5-year plans (Blandon 1983). The system, involving quantity targets and goals, expresses itself in log sales to the Pacific Rim countries. Five-year and one-year contracts that establish timber volumes are negotiated with customers. Prices are negotiated later on an annual and quarterly basis (Ogawa 1984). The current 5-year contract with Japan, which ends in 1985, covers about half the logs being purchased by Japan from U.S.S.R.

The quantity-first-price-later approach to marketing was mirrored in this study. It was assumed that quantities of logs moved from U.S.S.R. across the Pacific would not be influenced by prevailing prices, at least during the coming decade. The resulting set of supply curves is shown in figure 9. Shifts over time were based on the current 5-year plan and on an FAO projection (USDA Foreign Agricultural Service 1983c; United Nations, FAO 1982).

New Zealand

Wool, meat, and dairy products have been the mainstays of New Zealand exports for many years. They account for more than half the exports; forest products constitute 7 percent. Demand for primary commodities has been relatively flat during the 1975-85 decade. Productivity growth in other sectors has been low. These factors have combined to hold New Zealand per capita GNP almost constant at about $7,700; lower than that of Japan ($10,100) and Canada ($11,400) but substantially larger than most other Pacific Rim countries.[2/]

After removal of native forests New Zealand undertook a major program of reforestation with radiata pine. A program of short-rotation forestry, including thinnings and pruning, extended from the late 1920's through the 1930's and resumed in the 1960's. The timing of future yields from these stands has been estimated in detail. A surge in harvests is expected in the latter half of the 1990's and is expected to continue indefinitely. New Zealand is looking toward these forests as an important source of foreign exchange, with export earnings as high as $500 million per year (1980 prices) by the turn of the century (New Zealand Forest Service 1980). If the rest of the country's economy remains constant, wood products will then comprise more than 14 percent of New Zealand exports.

[2/]Prices and income figures are in 1983 U.S. dollars unless indicated otherwise.

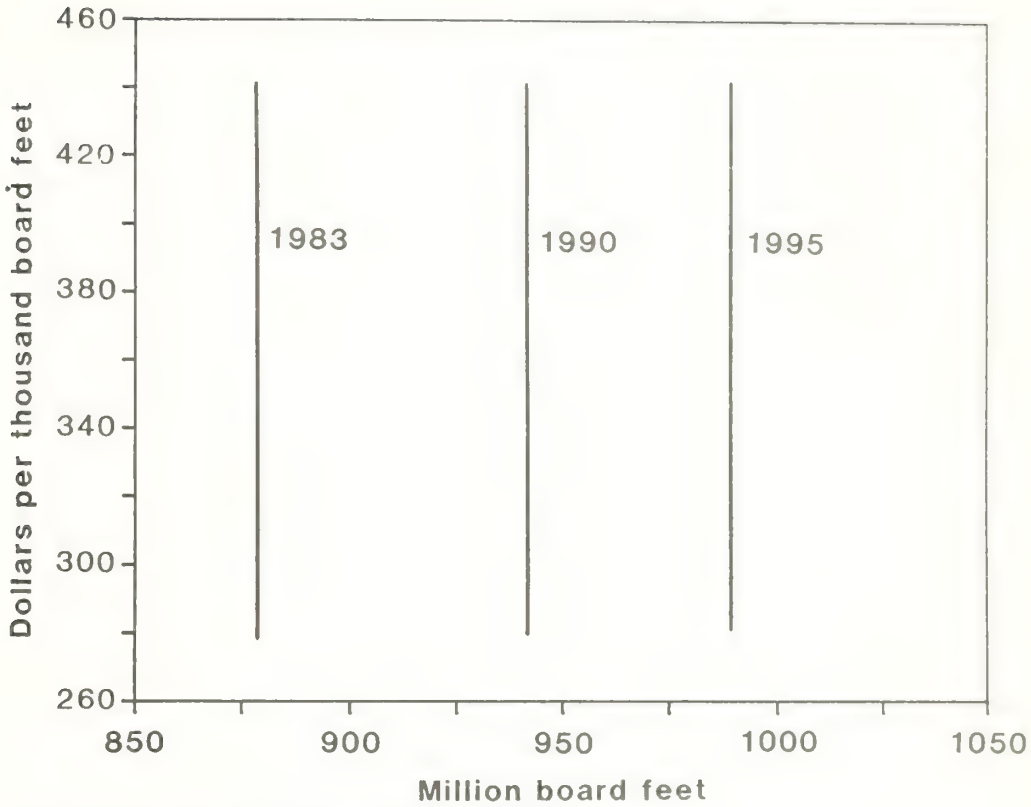

Figure 9.—Supply of construction-grade logs exported from U.S.S.R. Vertical lines indicate that quantities would not be affected by prices.

Log exports are already important. In 1980 overseas sales of logs and poles generated more than $60 million (f.o.b.—free on board) (New Zealand Forest Service 1984). In 1983 the comparable figure was about $40 million; the difference was due to reductions in volume, price, and the value of the New Zealand dollar.

New Zealand contributes about 6 percent of the construction-grade softwood logs that move among the Pacific Rim countries. Their cost seems low by U.S. standards, reflecting the relative values of the two currencies and quality considerations. Older stands, presently being cut, were mainly unpruned and therefore yield a much smaller fraction of clear woods than is expected in the future. There are concerns about strength, related to the rapid growth of radiata pine. In Japan, a major market, at least 70 percent of this species is used for boxes, crates, and packing materials (Japan Forestry Agency 1983).

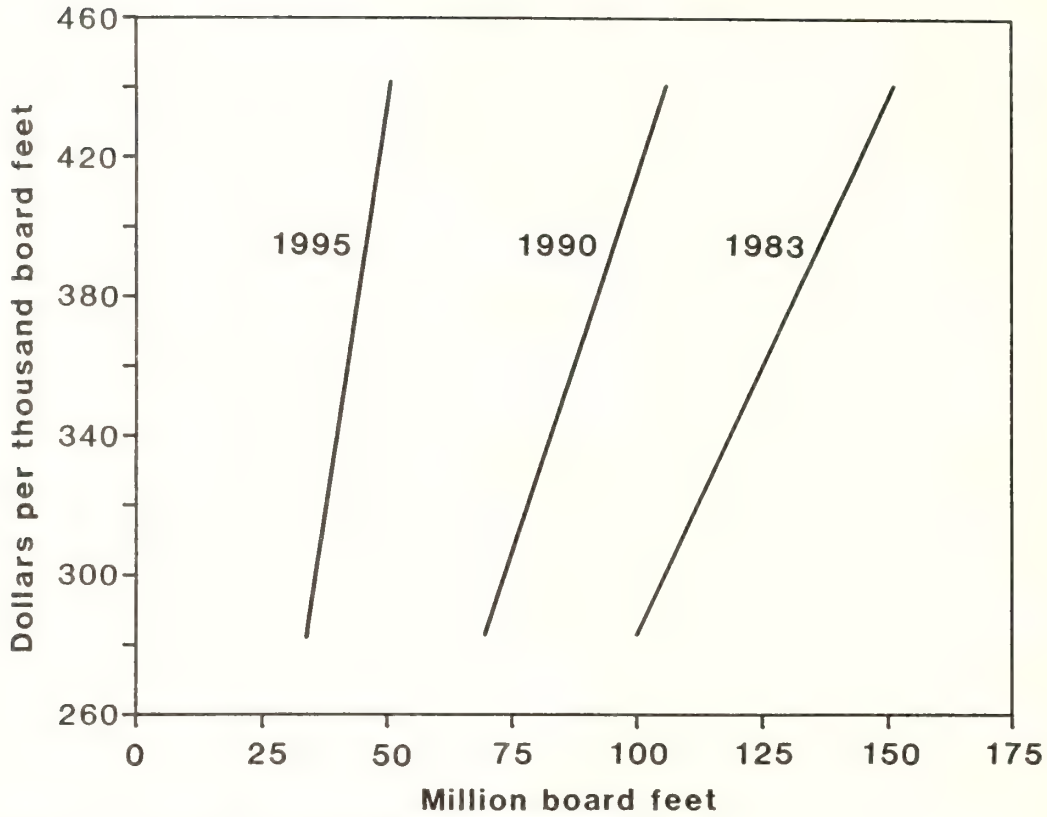

Figure 10.—Supply of construction-grade logs exported from New Zealand. Quantities exported are expected to decline through 1995.

Figure 10 shows the supply estimates made for New Zealand. Exports of construction-grade logs are expected to decline over the next decade, almost regardless of Pacific Rim log prices. There are two reasons. Steadily growing GNP will draw domestic timber into domestic uses; a World Bank (1984) projection of real gross domestic product growth at 2.5 percent per year was adopted. The second, and most significant, reason is that New Zealand's strategic planning and marketing efforts will increase acceptance of radiata pine for structural uses, moving 25 percent of the material here classed as "construction-grade" into higher value uses by 1990 and 50 percent by 1995. The result is greater roundwood export earnings despite a volume shrinkage in the log category studied here.

Not shown is the surge of supply that appears inevitable after 1995. New Zealand has 10 years to promote demand for the new generation of radiata pine products and to make decisions about the relative merits of pulp, plywood, lumber, and log exports.

Chile

During the early 1980's the economy of Chile was troubled by low recession-related copper prices and inflation greater than 20 percent. The country's difficulties in repaying foreign loans led to significant austerity programs. Gross domestic product per person in 1983 was about $1,700. On the other hand, currency devaluation generated a positive trade balance, and exports are almost 15 percent of GDP.

Despite weak world markets for wood-based commodities, forest products were the third most important source of foreign exchange in Chile in 1983; they accounted for about 8 percent of exports (The Economist Intelligence Unit 1984a).

In 1983 logs constituted only about 10 percent of forest products exports (The Economist Intelligence Unit 1984b). The logs were virtually all radiata pine; most went to Korea, Japan, and China (USDA Foreign Agricultural Service 1983a). Like New Zealand, Chile looks toward radiata pine as a major producer of foreign exchange later in the century. The government hopes to increase export earnings from wood products by sixfold in the late 1990's (The Economist Intelligence Unit 1984b). Chile plans harvest at earlier timber ages than does New Zealand and with relatively little thinning or pruning. The area of plantations created each year has more than doubled since 1974 (Chile Instituto Forestal and Corporacion Nacionel Forestal 1984a).

The projected supply curves for Chile are shown in figure 11. Estimates of the increase in supply in the 1990's range from doubling (USDA Foreign Agricultural Service 1983a) to quadrupling (Husch 1982). These estimates, however, relate to harvests; the increase in log exports was assumed to be at the upper end of this range because of delays in Chile's ability to gain the foreign investment needed for infrastructure and wood products manufacturing capacity. In 1990, 10 percent of log exports from Chile were assumed to be accepted into structural uses; this figure was increased to only 12 percent in 1995 because of relatively short rotations and the recent interruption of intensive forest culture.

Canada

British Columbia's prohibition of log exports from Crown lands limited Canadian offshore log exports to less than 100 million board feet per year (Council of Forest Industries of British Columbia 1985) through 1978. During the recession, exemptions granted on an individual-lot basis, generated by poor domestic markets, raised offshore exports from the west coast of Canada more than fivefold between 1978 and 1984, an average increase of 33 percent per year.

New export rules, currently being elaborated, provide for predesignation of stands and large tracts that contain timber economically unattractive to domestic markets. By permitting a longer term assessment of supplies available to export, trading firms will gain several advantages. Buyers will be able to judge handling and transport needs and to arrange resale in an orderly manner in their countries. Timber operators and sellers can gear themselves to stable expectations.

In the short run, foreknowledge should make f.a.s. log supplies more elastic because of increased flexibility in the timing of overseas shipment. Depending on rules yet unwritten, sales during periods of rising prices could possibly be delayed. In the longer term, the effect of predesignation on price responsiveness will depend on whether designations will be withdrawn in response to higher domestic prices, what the tenure of designations will be, and how quickly designations can be established during declines in the domestic market.

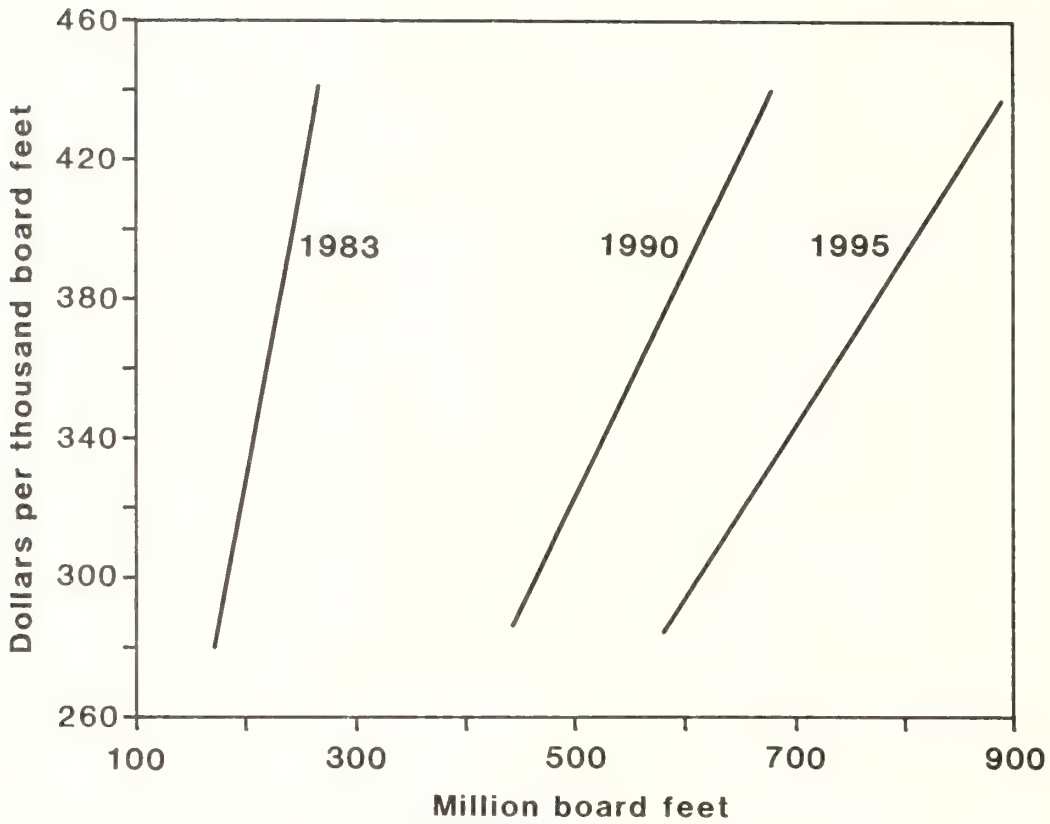

Figure 11.—Supply of construction-grade logs exported from Chile.

Because an increase was expected in short-term elasticity, a price elasticity estimate was drawn from Canadian lumber exports to the offshore Pacific Rim. The estimate, 0.57, is roughly midway between the absolute inelasticity implied by quantity controls and the elasticity estimated for U.S. log exports, 1.0. Figure 12 portrays the resulting supply curves. It was assumed that the upward trend in Canadian log exports will stabilize, and that of this volume about 130 million board feet of construction-grade logs will be exported to countries outside North America.

Substantially different conclusions can be drawn about the volume of construction-grade logs that will be permitted to leave British Columbia and the volume that can be recovered economically from predesignated stands.[3] The volume assumptions of this study are considered to be near the lower end of the speculative spectrum.

[3] Flora, Donald F.; Vlosky, Richard P. An equilibrium model of Pacific Rim trade in small logs. 1985. Manuscript on file. Seattle, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

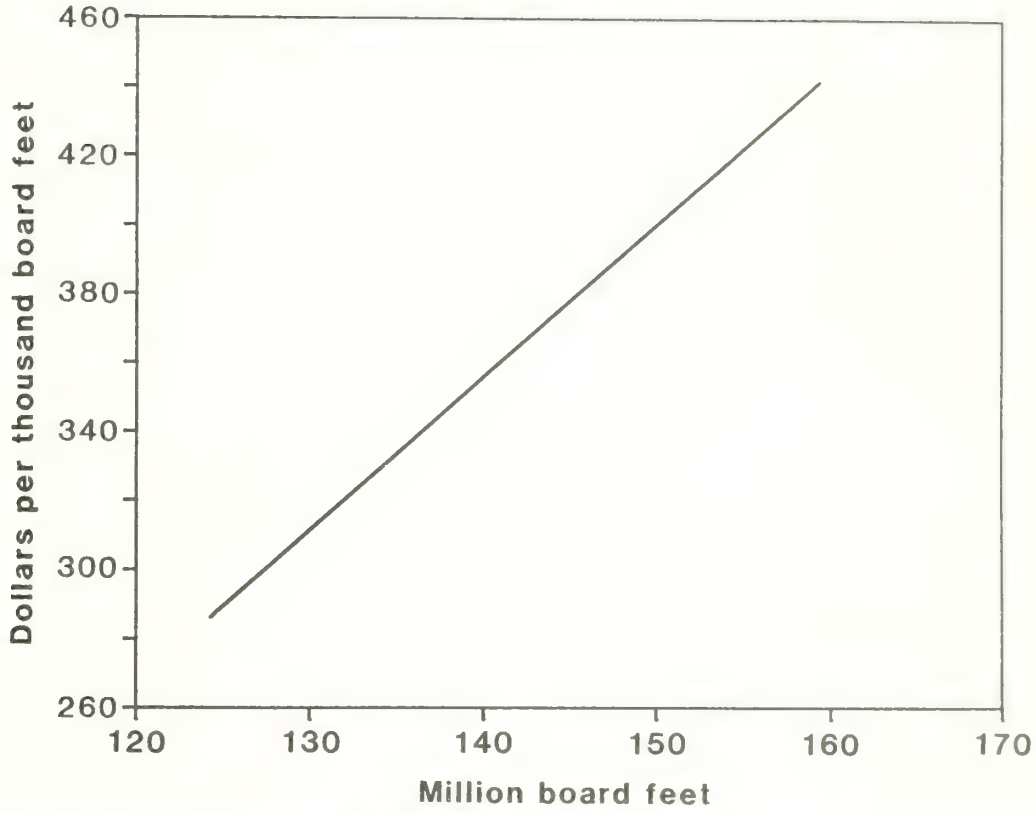

Figure 12.—Supply of construction-grade logs exported from Canada. The relationship of prices to quantities is projected to be constant through 1995.

Results

The aggregate Pacific Rim supply curve crosses the aggregate demand curve at $300/MBF for 1983 in figure 1. Considering that the aggregate curves were summed from several individual curves, most of which were fit stochastically and therefore have no precise locus, the intersection is satisfactorily close to the estimated volume-weighted export price of $290 in 1983. The "precision" of the aggregate volume estimate for 1983, 1.72 billion board feet log scale, is hard to check because construction-grade has no specific counterpart among grades used in the log trade.

Volume changes over time are estimated to be substantial. Exports (and imports) of construction-grade logs are estimated to expand 14 percent between 1983 and 1990, and 14 percent more in the next 5 years, indicated by the intersections in figure 2 and in figure 3. Total trade in this kind of logs is estimated to be about 2.2 billion board feet in 1990 and about 2.5 billion board feet in 1995.

Price changes are expected to be less substantial. Between 1983 and 1990 f.a.s. log prices are projected to increase 11 percent in real (inflation-adjusted) terms. Prices should be virtually constant during the early 1990's. In a preliminary analysis prices dropped almost 20 percent during the 1990-95 period, the result of an estimated price upsurge of almost 40 percent between 1983 and 1990. This estimated price gain disappeared with new, lower estimates of overseas demand and new, higher supply estimates for the 1990 supply for Chile.

Total spending on construction-grade logs (and total receipts for such logs) is projected to expand 41 percent between 1983 and 1990, and another 14 percent between 1990 and 1995. With increasing prices, even exporting countries that do not expand exports will experience rising log incomes.

Interval estimates of supply and demand elasticities in the aggregate construction-grade log markets are:

	1983	1990	1995
Supply	0.42	0.53	0.57
Demand	-.50	-.50	-.52

Construction-grade log exports and imports for individual countries are determined by using the Rim-wide equilibrium prices in each nation's equation, or by tracking the price graphically across the country's supply or demand curve. Estimated log flows are:

Country	1983	1990	1995
	(Million board feet)		
Imports:			
Japan	747	900	835
China	570	816	1,024
Korea	306	348	434
Taiwan	7	75	122
Exports:			
U.S.S.R.	877	940	988
United States	361	488	602
Canada	128	136	136
Chile	177	510	683
New Zealand	103	79	37

Conclusions

The Pacific Rim market for construction-grade logs is projected to expand significantly through 1995, with demand outpacing supply until 1990. For the subsequent half-decade, supply and demand should shift in concert. Effects on prices and log flows have been described earlier.

Total spending in 1983 dollars on this class of logs is expected to increase 70 percent during the 10 years; volume will increase 50 percent. The increase in prices will be an encouragement to intensive forestry, to development of small-log handling facilities, and to milling capacity geared to small material; the increased income will help facilitate these advances. On the other hand, the higher prices will tend to induce a search for substitutes even as they press users toward greater efficiency.

In the United States exporters of small logs are estimated to gain 3 percent (from 22 percent to 25 percent) in their share of the market. The higher prices and volumes, though, should increase payments to U.S. exporters about 90 percent. Export volume from the United States is projected to increase two-thirds for construction-grade logs.

Competitor countries are estimated to increase their export volume about 45 percent overall. Chile will generate the largest proportional gain (nearly fourfold is expected), as well as the largest absolute volume gain, about 0.5 billion board feet.

Among the consuming countries, China's imports are estimated to double by 1995, with a gain of 0.5 billion board feet. Japan's import growth is expected to be less vigorous, but quite significant, with a 12-percent gain attributable to a 90-million-board-foot increase. The absolute gains of Korea and Taiwan are projected to be comparable, at 130 million and 115 million board feet, respectively. For Korea this would be 42-percent growth; for Taiwan it would be a near-infinite change percentagewise because of negligible 1983 purchases.

For the importing countries, the implications for industrial structure and port facilities vary greatly. For Japan the increase would probably be treated as business as usual because the percentage change is not large and because construction-grade logs constitute only about one-third of their log imports. In Korea and Taiwan the effect on port activity may not be significant because of an offsetting decline in hardwood log imports. China, though, is already moving to expand coastal log-handling capabilities.

The rationale for Japan applies also to U.S. coastal facilities because this log class is only about 15 percent of all log exports. For Chile, though, quadrupling of roundwood sales would have important consequences for waterside transport and employment.

With elasticities of about 0.5, both exports and imports are price-sensitive at the aggregate, Pacific-Rim level. Conversely, a significant shift in supply or demand caused, say, by a change in international trade policies or a general rise in freight rates, should have appreciable effects on log prices.

Conversion Factors

Because the average size of construction-grade logs varies among countries, the relationship of board-foot volume to cubic meters varies also. Figures 4 through 12, and their companion equations, can be converted to dollars per cubic meter and thousand cubic meters as follows:

	Dollars per MBF to dollars per cubic meter, multiply by:	Million board feet to thousand cubic meters, multiply by:
Japan	0.18	0.0055
Korea	0.17	0.0060
China	0.17	0.0060
Taiwan	0.18	0.0055
United States	0.18	0.0055
Soviet Union	0.17	0.0060
New Zealand	0.18	0.0055
Chile	0.18	0.0055
Canada	0.22	0.0045

Conversion factors for figures 1 through 3 vary slightly within each figure, depending on the changing relative quantities associated with each country, as total Pacific Rim quantities change along the graphs. Reasonable approximations are 0.18 and 0.0055.

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Appendix

This section covers the mathematical formulation of demand and/or supply functions and their aggregation for individual countries.

Q is quantity in thousand cubic meters. Unless otherwise noted, a conversion of 5.5 cubic meters per thousand board feet (MBF), Scribner log scale, is appropriate.
p is price in local (non-U.S.) currency per cubic meter, c.i.f. the country's port, inflation-adjusted to 1983.
P is price per cubic meter in 1983 U.S. dollars, adjusted for shipping cost to f.a.s. North America; International Monetary Fund currency conversion factors are used unless otherwise indicated.
G is the country's gross national product (GNP) or gross domestic product (GDP), inflation-adjusted to 1983 prices, in units of currency shown with the equation.

Equations were developed by use of ordinary least squares. Shown in parentheses below the coefficients to which they apply are the "t" statistics. R^2 and DW are the coefficient of determination and the Durbin-Watson statistic, respectively. The country analyses were done in local currency, then equations were adjusted to f.a.s. and U.S. dollars.

Annual data were used throughout the analyses. Except as indicated, the sample period is 1963-82. Dummy variables were used to recognize major currency realignments and other major structural economic changes in log markets. Lagged variables were not used. Commonality was sought among the variables used for different nations. And variables were included only if a plausible means of forecasting them through 1995 was apparent. Overall, some explanatory power was sacrificed for simplicity. For example, Wiseman [1/] developed a demand equation for U.S. logs in Japan by using an 18-year data series and four predictive variables, achieving an R^2 of 0.98. The comparable equation in this study used two explanatory variables and yielded an R^2 of 0.78.

Japan

The demand equation for Japan is:

$$Q = 1528 - 0.0578p + 3.51S$$
$$\qquad\qquad (-1.10) \qquad (4.07)$$

$R^2 = 0.78$; DW = 1.62; F = 14.

S = housing starts, in thousands.

p = hundred yen per cubic meter.

Adjusted from c.i.f. and local prices to f.a.s. and dollars, it is:

$$Q = 1201 - 13.87P + 3.51S.$$

The price elasticity of this function, at 1983 quantity and price, is -0.24.

[1/]Wiseman, A. Clark. The role of prices and foreign trade barriers in affecting the volume of United States forest products exports. 1983. Report on file. Seattle, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Korea

The demand equation for Korea is:

$$Q = -1762 - 2393 \ln p + 1393 \ln G$$
$$(-2.40) \qquad (3.58)$$

$R^2 = 0.77$; DW = 1.06; F = 15.

G = GDP in billion won.

Adjusted from c.i.f. to f.a.s., and from won to dollars, it is:

$$Q = -1762 - 2393 \ln(P + 25) + 1393 \ln G$$

G remains in billion won.

Data used were for 1971-82.

The projections of gross domestic product were 1.6 percent per year through 1985, and 5.5 percent per year thereafter (World Bank 1984).

Taiwan

Aggregate excess demand for imported logs was taken to be the difference between rising domestic consumption and falling domestic production. These components were estimated separately in the absence of historic evidence on softwood log imports.

With a "t" value of only 0.19 for the price coefficient, the demand equation was judged unfit for projections (the equation, using GNP as a shifter, had an F value of 17 and an R^2 of 0.81). Instead, a price elasticity estimate was based on another, in which elasticity (E) was between 0.7 and 1.3 (Jen 1982). A midpoint elasticity, 1.0, was used with the price and quantity for 1983 to formulate the local demand function:

$$\ln Q = 14.24 - 1.0 \ln p + 0.055 N$$

p = NT$ per cubic meter.

N = date (year) minus 1983.

The variable N is a demand shifter developed from the assumptions that demand will increase in concert with gross national product and that GNP will increase 5.7 percent per year in real terms (World Bank 1984).

The corresponding f.a.s. function is:

$$\ln Q = 10.55 - \ln(P + 27.8) + 0.055 N$$

The local supply function for Taiwan is founded on that country's longstanding reliance on domestically grown softwoods, a source that is declining as is evidenced by rising prices and falling volumes sold. Analytically, the evidence is in a leftward-shifting supply curve:

$$\ln Q = 3.5112 + 0.31 \ln p - 0.1158 N$$
$$(2.38) \quad (-6.18)$$

$R^2 = 0.95$; DW = 2.70; F = 71.

p = Taiwan dollars per cubic meter;

N = date (year) minus 1983.

Adjusted to U.S. funds and f.a.s. supply, the equation is:

$$\ln Q = 4.6548 + 0.31 \ln(P + 37) - 0.1158 N$$

The data were for 1971-81.

China

Assumptions described in the text produce this f.a.s. demand equation:

$$Q = K/(P + 27);$$

K = 280,000 in 1983; 430,000 in 1990; and 570,000 in 1995.

United States

The f.a.s. supply equation is:

$$\ln Q = 1.23 + 1.0 \ln P + 0.065C + 0.039N + 0.58D$$
$$(0.96) \quad (3.03) \quad (4.71) \quad (6.45)$$

$R^2 = 0.96$; DW = 2.85; F = 88.

C = Pacific Northwest timber cut, billion board feet;

N = date, year minus 1960;

D = dummy = 1 after 1966.

Soviet Union

The price-invariant function adds 1 percent per year to Soviet log exports into the Pacific area. For 1983 the quantity estimate is based on Soviet data reported by the USDA Foreign Agricultural Service (1984). The projected growth rate in exports is centered among various estimates bounded by the Soviet Eleventh Five-Year Plan (timber production increasing 0.5 percent per year) and an FAO estimate of export gains of 1.3 percent per annum (USDA Foreign Agricultural Service 1983c; United Nations, FAO 1982).

The resulting equation is:

$$\ln Q = 8.568 + 0.01 N;$$

N = date (year) minus 1983.

New Zealand

The supply function for construction-grade log exports for New Zealand is:

$$\ln Q = 4.766 + 0.97 \ln p + 0.00019C - 0.00018G - 0.415D$$
$$\qquad\qquad (0.65) \qquad (0.91) \qquad (-1.53) \qquad (-1.14)$$

$R^2 = 0.53$; DW = 1.03; F = 3.1.

Data period is 1968-83.

p = New Zealand dollars per cubic meter;

C = softwood log harvest, in thousand cubic meters;

G = GDP, 1980 prices, million New Zealand dollars;

D = dummy = 1 after 1975.

Harvest forecasts were drawn from a New Zealand Forest Service (1980) report.

The descriptive weakness of this equation, with particular regard to the price coefficient, should be noted. Exports have not been well correlated with log prices.

Because shipping costs to most Pacific Rim markets were assumed lower than, but not materially different from, rates from the U.S. west coast, a separate f.a.s. function was not needed.

Chile

Data for 1975-83 were used to develop a relationship between log export volume, harvest, and GDP:

$$Q = -515 + 0.276C - 0.734G$$
$$\qquad\qquad (2.56) \quad (-1.29)$$

$R^2 = 0.77$; F = 8.4.

C = industrial log consumption, assumed equal to harvest, in thousand cubic meters (Chile Instituto Forestal 1984a);

G = GDP at 1980 prices, in billion pesos.

Attempts to incorporate a price variable failed to produce statistically valid coefficients. Therefore a short-term price elasticity of 1.0 was imposed.

Projections of harvest were drawn from a study in Chile of radiata pine production trends (Chile Instituto Forestal 1984b). The World Bank (1984) provided the basis for assuming GDP growth of 1.9 percent annually to 1985 and 3.8 percent per year thereafter.

Ten percent of Chilean pine exports were assumed to be "structural" grade by 1990 and 12 percent in the more valuable "structural" category by 1995. Resulting export quantities are 15 to 30 percent higher than projected in the Chile mensurational study. The latter estimates, however, are derived from an assumption that 22 percent of saw logs in Chile will enter export markets. This is a lower fraction than was experienced prior to 1985. Certainly an urgent need for foreign exchange and static investment in domestic processing facilities will create pressure toward roundwood sales abroad.

Estimated harvests in Chile and export quantities at 1983 prices are:

	Harvest[2]	Export
	(Thousand cubic meters)	
1983	10,880	950
1990	17,710	2,460
1995	21,880	3,270

Canada

The supply function is:

$$\ln Q = 3.958 + 0.57 \ln P.$$

[2/]Chile Instituto Forestal (1984b).

Flora, Donald F.; Vlosky, Richard P. Potential Pacific Rim demand for construction-grade softwood logs. Res. Pap. PNW-364. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 29 p.

Markets for small lower grade ("construction-grade"), softwood logs are projected to expand steadily through 1995. Log supplies will lag slightly behind demand until 1990, generating about a 10-percent increase in prices. Prices are expected to be level thereafter. United States exports of construction-grade logs are projected to increase 35 percent by 1990 and another 23 percent by 1995.

Keywords: Markets (external), supply/demand (forest products), trade (Pacific Rim).

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Growth and Yield of Western Hemlock in the Pacific Northwest Following Thinning Near the Time of Initial Crown Closing

Gerald E. Hoyer and Jon D. Swanzy

CLEMSON UNIVERSITY 1987 GOVERNMENT DOCUMENTS

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Abstract

Hoyer, Gerald E.; Swanzy, Jon D. Growth and yield of western hemlock in the Pacific Northwest following thinning near the time of initial crown closure. Res. Pap. PNW-365. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 52 p.

Growth, stand development, and yield were studied for young, thinned western hemlock (*Tsuga heterophylla* Raf. [Sarg.]). Two similar studies were located at Cascade Head Experimental Forest in the Siuslaw National Forest, western Oregon, and near Clallam Bay on the Olympic Peninsula in Washington. At the latter, first thinnings were made at two ages; one at about the time of initial crown closure (early or crown-closure thinning), and the other after competition was well underway (late or competition thinning).

Stands, age 7 at breast height at time of crown closure thinning, were grown for 17 years at Cascade Head and for 11 years at Clallam Bay. In addition, 6 years after (early) crown-closure thinning the first (late) competition thinning was made at Clallam Bay on previously prepared, well-stocked stands. The tree spacing on the early thinnings ranged from 3 feet to 22 feet.

At ages 24 and 18 breast height on the two studies, stands with the most stocking produced the most cubic-foot volume and volume increment and the smallest average diameter. Early thinnings spaced between 7 and 12 feet produced the most usable wood in terms of Scribner board-foot volume of trees 6 inches in diameter and larger.

During the 6-year period following the late thinning, the treatments produced 55, 86, and 180 more cubic-foot volume increment per acre per year than did early thinnings that grew to the same basal area. The studies provide an approximation of the behavior of stands grown at given plantation spacings. The studies suggest that volume increment from stands thinned late differs from the volume increment of early thinning or planted stands that have attained basal area density similar to the late-thinned stands. Representative growth and yield data is provided for all treatments.

Keywords: Spacing thinnings, stand development, increment, yield (forest), western hemlock.

Summary

Western hemlock is a major timber species in western Oregon and Washington so forest managers need to understand the growth and development of hemlock stands grown from a wide range of plantation spacings. Of equal interest is behavior of stands thinned after crown closure when competition is well underway. These conditions were tested with studies in two stands, one with a site index (50-year base) of 109 feet at Cascade Head Experimental Forest, Oregon, the other with a site index of 123 feet near Clallam Bay, Washington. Both studies were age 7 at breast height (12 and 11, respectively, in terms of total age) when treatment thinnings began. Because crowns had just closed and competition had just begun, trees remaining after thinning were essentially free of competition. The trees are considered here to be nearly equivalent in growth to trees that were free to grow since stand establishment (that is, approximately equivalent to trees grown from plantation spacing). The Cascade Head study was installed in 1964, the Clallam Bay study in 1971.

The two studies were compatible but not identical. At Cascade Head, treatments included one unthinned nominal 3-foot control plot and 8-, 12-, 16-, and 20-foot, carefully selected spaced thinnings.

At Clallam Bay, basal area rather than nominal spacing distance was the plot control variable. Resulting tree spacings were a 4-foot spaced control, and nominal 7.4-, 9.2-, 12.3-, 17.6-, and 21.8-foot thinning treatments. All Clallam Bay plots were thinned to a 4.0-foot spacing distance and grown for 2 years to stabilize the stand before final treatment thinning. Six years after crown-closure thinning, selected plots growing from 4- and 7.4-foot spacings were thinned to the level of basal area reached by the 9.2-foot, spaced, crown-closure thinning.

For the study period, crown-closure thinning did not influence the average height growth of the site index trees. Ingrowth was high on the widest spacings. There has been some continuing mortality of original trees even on the widest spacings. Plots at 8-foot and closer spacings have lost trees to competition mortality. Plots at wider spacings have lost trees to other causes. Tree death from *Armillaria* root rot is serious on some treatments at Clallam Bay, probably a result of early debarking by mountain beaver of tree roots and stems near the ground.

Spacing treatments have altered tree form to the extent that tree volume is not correctly estimated by a conventional equation using tree diameter and height. A measured form factor is needed to gain volume estimation precision.

Gross current annual basal area increment reached a maximum below age 20 for the more closely spaced treatments on both studies; increment for the wider spacings did not. Gross current annual cubic-foot volume increment has not reached a maximum yet. Trees growing at spacings of 16 feet and wider have free-growing diameter increment; trees at closer spacings have some degree of diameter restriction. The closest spacings produced the most cubic-foot yield and increment. Currently, spacings between 7 and 12 feet are producing superior Scribner board-foot yields and will probably continue to do so for the immediate future.

The rapid diameter growth of trees at wide spacings has produced wood with fewer than four rings per inch of diameter. These are the central cores on which higher quality wood is now growing.

During the 6 years following cutting, the competition-thinning stands averaged 55, 86, and 180 more cubic-foot volume increment per acre per year than did the crown-closure thinning stand of the same basal area. These increases in volume increment could not be explained by differences in basal area, relative density, number of stems per acre, average diameter, or height. Something in addition is needed. Results discourage the idea that growth following competition thinning of hemlock stands is about the same as growth following crown-closure thinnings (and, by extension, plantations) of stands with the same attained basal area.

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Introduction

Early and Late Thinning in Western Hemlock

Western hemlock (*Tsuga heterophylla* Raf. [Sarg.]) is a major timber species in western Oregon and Washington, and conversion from old-growth forests to regenerated second-growth forests is well underway. These new young forests are highly productive, a fact recognized by forest managers. Managers need to know how this productivity can be altered by thinning to control tree spacing at young ages.

At almost any year during the first 25 years of a young forest stand, the manager could thin to specified distances between trees (spacing). Both the stand age and the spacing between remaining trees are subject to the manager's choice. We define two thinning ages here.

We consider "early" thinning as a thinning made at about the time of first crown closure when tree competition is just beginning; and we use the terms "early" and "crown-closure thinning" interchangeably to describe this case. Two stands, at total ages 11 and 12, that were studied for this report had early thinnings.

Trees remaining after early thinning have been nearly free growing from the time of establishment and will continue to be free growing until effects of the early thinning are gone and tree crowns close. Thus, tree growth following early thinning can be thought of as similar to growth of trees as if they had been planted at the spacing to which they have been thinned. We define "late" thinning as one made in a stand after competition is well under way. Stands older than about total age 15 are late thinnings. We use the terms "late thinning" and "competition thinning" interchangeably to describe this case.

Both early and late thinnings can be further described according to the nominal spacing distance between trees after the thinnings have been made. The plots in the studies were thinned to several different nominal tree spacings according to specific prescribed treatments in each study. A given thinning treatment can be conveniently referred to by its nominal spacing distance. Thus, "early thinning to 12 feet," and "early thinning at 12-foot spacing" describe the same treatment. We use these two terms, "thinning" and "spacing," interchangeably in this manner and consider both as treatments.

The opportunities for early and late thinning lead to questions by forest managers:

1. Does early (crown-closure) thinning to various tree spacings produce important differences in growth, yield, and product size as compared to different spacings and to nonthinned stands?

2. If stands are not thinned early at time of crown-closure, but are thinned later after competition is well underway, how do growth, yield, and product size compare with stands that were thinned at the time of crown-closure?

The purpose of this study was to answer these questions.

Results From the Literature

Results of early thinning of various tree species are common in the literature, and from this background we expected several things to occur as a result of early thinning in western hemlock. We expected individual tree basal area and volume to increase with wider spacing; we expected total cubic-volume productivity to be highest with the densest spacing, unless stagnation occurred; and because western hemlock grows well in shaded conditions, we expected no stagnation in the closer tree spacings used in the study. We expected stands grown at wider spacings would have a greater proportion of volume in trees of larger diameter.

Thinning trees to wider spacing might alter tree height in western hemlock, as Reukema (1979) found for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). Also, the diameter response to wider spacing alters the form of the tree. We expected a measurable difference in form quotient among trees grown at various spacings.

The best known plantation spacing study in the Pacific Northwest is the Wind River spacing trial for Douglas-fir located in the Wind River Experimental Forest, Gifford Pinchot National Forest, in southwestern Washington (Reukema 1979). Results from that study show the dramatic impact that early wide plantation spacing has on ultimate tree size, volume, and volume distribution. Western hemlock is known to respond well to thinning (Dilworth 1980, Malmberg 1965). We expected significant response to early thinning because of western hemlock's rapid growth and ability to respond to increased light.

Pienaar and Turnbull (1973) show that the growth and yield of thinned stands can be estimated using curve trends and inflection points from plantations (or very early spacings) grown from a range of spacing distances. Such trends along with estimates of ultimate yield are used in growth models. Stands thinned at about 10 years of age reach maximum basal area increment in the 10 years following thinning. These culmination points help estimate later growth trends as defined by the selected model. The plots in these studies were expected to help define such trends.

Materials and Methods

Two Study Areas

Two study areas were involved in the experiment. USDA Forest Service scientists installed one at the Cascade Head Experimental Forest, Siuslaw National Forest, Oregon, following the 1963 growing season; we installed the other near the town of Clallam Bay, Washington, in 1969. Design of the two studies was similar and compatible but not identical. We describe them separately in this report but combined their similar results.

The Cascade Head study had only early (crown-closure) thinning treatments and only one control plot. Standard spacing distances ranging from 7 to 20 feet were used to select the trees to leave. At Clallam Bay, on the other hand, early thinnings had a wider range of nominal spacings, from 4 to 22 feet.

The criterion for thinning at Clallam Bay was basal area; the number of stems per acre and, hence, spacing varied. In addition, Clallam Bay had several control plots as part of the experiment. We prepared all plots with a calibration thinning to 4-foot spacing and allowed plots to stabilize by growing for 2 years before the treatment thinning began. Two plots at 4-foot spacing were spaced controls. We also installed plots in an untouched area as an absolute control.

The Clallam Bay study included treatments that were not used in the Cascade Head study. At the time of the early thinning we set aside plots to be used later as a comparable late thinning. The intent was to thin late to the level of basal area reached by early crown-closure thinning treatments. Thus, early and late thinning and the growth therefrom could be directly compared on stands that were the same to begin with.

Cascade Head Study: General Description

The Cascade Head study is in the coastal hemlock zone of western Oregon (fig. 1). Plots were installed at 500 feet elevation on a nearly level site across the top of a gentle rise with slight northeast and southwest aspects. Average annual precipitation, almost all in the form of rain, is approximately 89 inches. There is frequent summer moisture from fog drip. Average annual temperature is about 50 °F.

Soils in the general area are classified as Astoria silty clay or clay loam, which are representative of the reddish-brown latosol suborder of the great soil groups. Soils have formed over tuffaceous siltstones, although basalt bedrock sometimes causes significant local modifications to the soil profile. Soil depth ranges from 2 to 6 feet. Small stones are scattered thinly through the profile. Soils are strongly acidic and humus develops rapidly. The forest floor is usually less than 2 inches thick, but the A1 horizon generally extends to 4 inches or more.

The stand used in the study had been regenerated as an experimental shelterwood cutting under an overstory stand that was logged in 1962. In 1978, increment core borings were extracted from site index sample trees that represented the upper 20 percent of plot diameter ranges. These trees were approximately 2 years older than the average stand age. There was a 4-year range among plots as well. We assigned a nominal average stand age of 12 years total and 7 years breast height for the trees at the time of the study installation in 1963 and report the same in the appendix tables. We computed average plot age by subtracting 2 years from the average age of the site index sample trees and used this in analyses where plot age was a variable.

The study included four treatments: 8-, 12-, 16- and 20-foot nominal spacings and one control plot (fig. 2). The study was a randomized block design with two blocks. A summary of average treatment statistics appears in table 1.

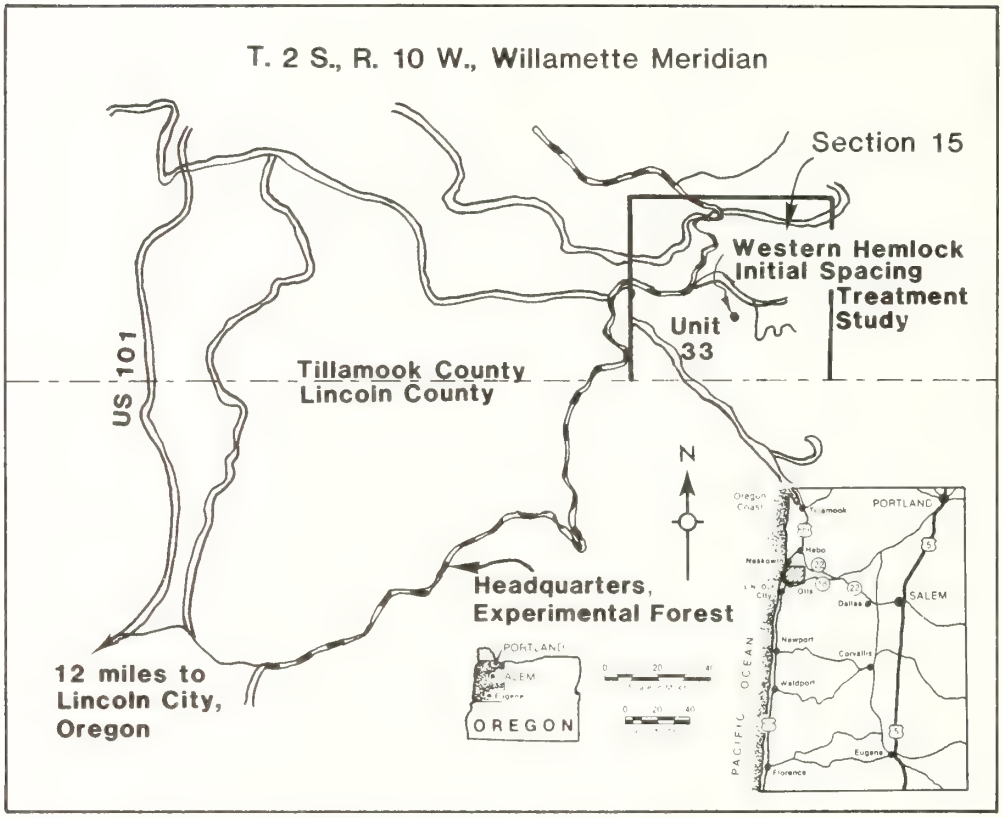

Figure 1.—Vicinity map of the western hemlock spacing treatment study at Cascade Head Experimental Forest, Oregon.

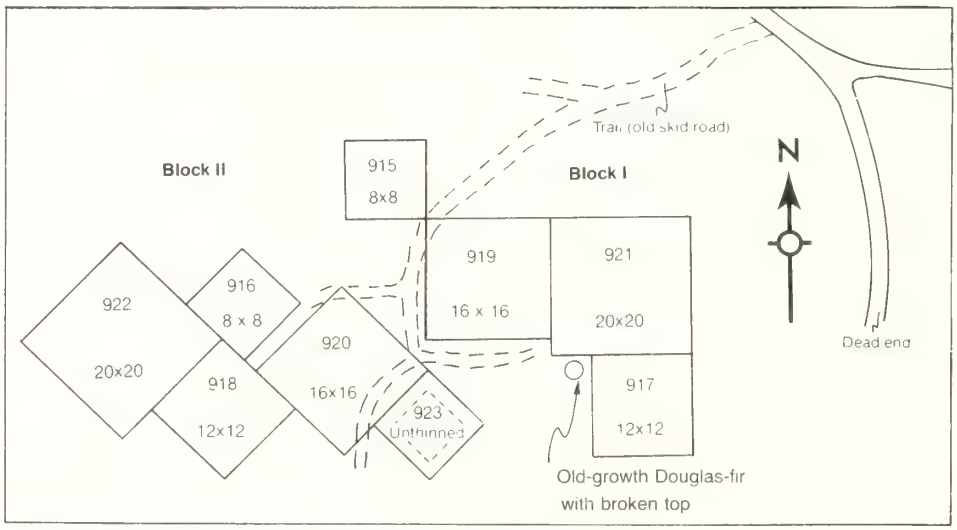

Figure 2.—Western hemlock spacing treatment plots, plot numbers, and nominal spacing in feet, Cascade Head Experimental Forest.

Table 1—Average statistics per acre, by treatment and plot, for selected years, Cascade Head, Oregon

Treatment and plot number	Site index	1980, total age 29						1979 live crown ratio	1961, total age 1		
		Height of site trees	Cubic-foot volume	Number of stems	Basal area	Mean DBH 1/	Board-foot volume 2/		Initial spacing	Number of stems	Basal area
		Feet	Thousand cubic feet		Square feet	Inches	Thousand board feet		Feet		Square feet
Control:											
923	122	75.9	10.6	1,201	330	7.1	23.8	0.52	3.4	4,004	115.0
8-foot spacing:											
915	114	70.9	5.3	538	179	7.8	14.0	.48	9.0	538	12.2
916	104	66.0	7.3	465	238	9.7	24.8	.56	8.9	553	13.7
Average	109	68.5	6.3	501	209	8.8	19.4	.52	9.0	546	13.0
12-foot spacing:											
917	112	67.8	4.5	278	164	10.4	16.2	.67	12.0	302	8.2
918	116	67.7	5.6	278	198	11.4	20.7	.62	12.0	302	8.1
Average	114	67.8	5.0	278	181	10.9	18.5	.64	12.0	302	8.2
16-foot spacing:											
919	111	65.5	3.5	170	129	12.0	13.7	.62	16.0	170	3.7
920	107	65.1	3.8	150	136	12.9	15.6	.66	16.0	170	5.6
Average	109	65.3	3.7	160	133	12.5	14.6	.64	16.0	170	4.6
20-foot spacing:											
921	109	65.7	2.6	109	99	12.9	10.3	.75	20.0	109	2.1
922	103	61.8	2.0	100	77	11.9	7.4	.76	20.0	109	2.0
Average	106	63.7	2.3	105	88	12.4	8.9	.76	20.0	109	2.0

1/ DBH is diameter at breast height, 4.5 feet above ground.

2/ Board-foot volume is Scribner scale to a 6-inch merchantable top diameter.

Clallam Bay: General Description

The Clallam Bay study was installed on a site at 400 feet elevation with a 15 percent slope and northeasterly aspect in the coastal western hemlock zone (fig. 3). The site faces the Strait of Juan de Fuca and is protected somewhat from the full force of Pacific Ocean storms. Average annual temperature at the weather station at the town of Clallam Bay is 48 °F and average annual precipitation is 79 inches. Soil on the site is an Ozette silt loam formed on undulating glacial till. It is 27 inches deep, is moderately well drained, and has a 9-inch A-horizon.

The study area had regenerated to a nearly pure western hemlock stand following logging. Regeneration was advanced understory trees, some newly seeded hemlock stock, and planted Douglas-fir. We removed the Douglas-fir in a subsequent treatment to produce a pure western hemlock stand.

After the 1971 growing season, we cut trees (from areas adjacent to the study plot) that were the same diameter and height as trees on the plots and counted rings at breast height and at the ground level. Based on these counts the average age of trees in the area was 7 years breast height and 11 years total. Individual plot age varied 1 year around the overall average age.

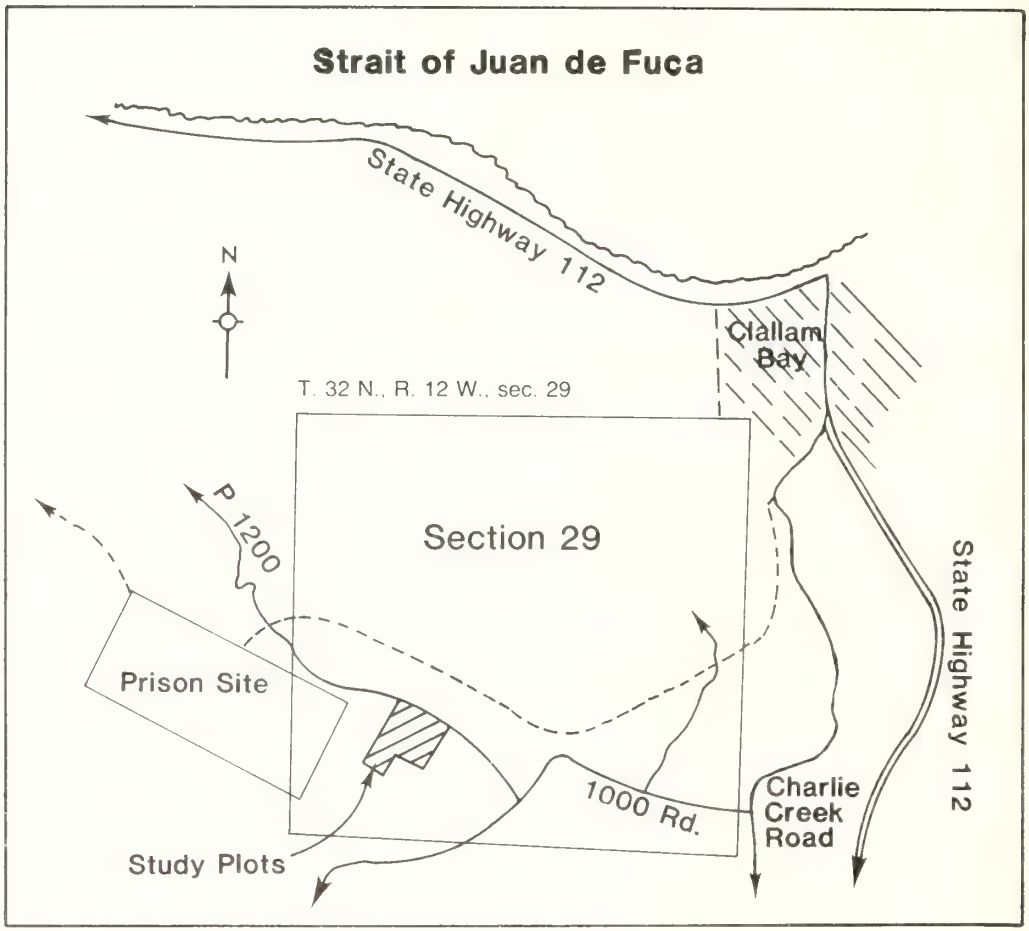

Figure 3.—Vicinity map of the western hemlock spacing treatment study near Clallam Bay, Washington

We selected 10 treatments for study. Six of the treatments were early thinnings cut in 1971 at age 11. The other four were late thinnings to be made at specified levels of basal area. All plots were assigned completely at random within the study area.

In addition to the 10 treatments, we maintained a control area that had not been thinned in any way. The area included a few planted Douglas-fir trees. Twelve 0.005-acre plots in this control area served to describe a sparse Douglas-fir plantation with naturally regenerated hemlock. We also added a single, late-thinned plot in this control area. These plots were helpful for comparisons but were not part of the original study plan design.

The treatments, their plot numbers, and statistics at the time of early thinning in 1971 and later thinning in 1977 are summarized in table 2. Figure 4 gives spacing, plot number, and locations for all plots in the Clallam Bay study.

Table 2—Average statistics per acre, by treatment and plot, for selected years, Clallam Bay, Washington

Treatment sequence and plot number	Site index	1977, 1982					1980		1971, age 11	
		Year	Height of site trees	Volume	Number of stems	Basal area	DBH 1/	Live crown ratio	Crown width	Number of stems	Basal area
	Feet		Feet	Thousand cubic feet		Square feet	Inches		Feet		Square feet
Nonspaced control (3.5 feet)	-	1982	51.1	8.3	5,000+	370	3.6	0.46		5,000+	70+
Nonspaced control, released to 7.4-foot at age 17 spacing; plot 354	111	1977 before cut			5,000	271					
	111	1977 after cut		.8	800	52	3.9				
	111	1982	46.0	3.2	800	151	5.9	.52			
4.0-foot spacing, plots 335 and 350	121	1982	47.6	4.8	1,569	215	4.4	.51	11	2,731	38.5
4.0-foot spacing, released to 8.0 feet at age 17; plots 352 and 353	125	1977 before cut			2,724	160	3.3				
	125	1977 after cut			655	72	4.4				
	125	1982	48.4	3.5	672	52	6.5	.66		2,604	40.4
7.4-foot spacing, plots 331, 332, 342, and 343	129	1982	50.3	4.1	687	81	6.9	.70		784	15.2
7.4-foot spacing, released; plots 344 and 345	127	1977 before cut			790	108	5.1	--			
	127	1977 after cut	--	--	472	77	6.0				
	127	1982	51.0	3.8	448	154	7.9	.71	--	857	15.7
9.2-foot spacing, plots 333 and 334	122	1982	46.7	2.9	394	30	7.8	.78	19	514	8.8
12.3-foot spacing, plots 336, 337, 346, 347, 348, and 349	124	1982	47.0	2.4	250	109	8.9	.77	22	287	5.1
17.6-foot spacing, plots 338 and 339	124	1982	46.8	1.5	158	69	9.8	.80	22	208	2.6
21.8-foot spacing, plots 340 and 341	121	1982	45.4	.9	83	45	9.9	.84	22	91	1.7

-- = measurements not made.

1/ DBH is diameter at breast height, 4.5 feet above the ground.

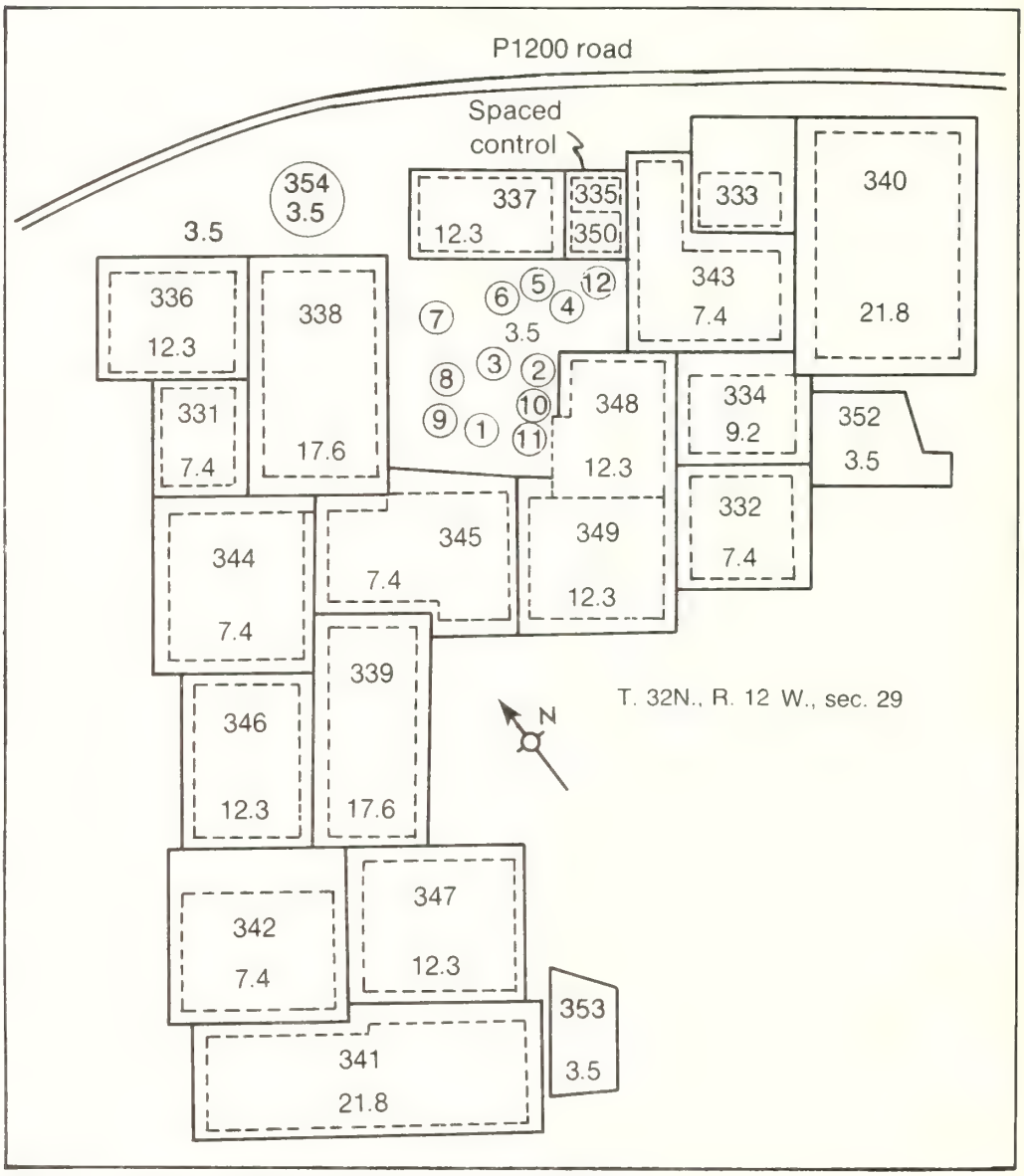

Figure 4.—Western hemlock spacing treatment plots, plot numbers, and nominal spacing in feet, Clallam Bay.

To help the reader compare details reported for the two studies, the logic used for organizing tabular data is mentioned here. The intent was to include data most likely to be directly compared either in the same table, where possible, or to place as adjacent "paired" tables, with Cascade Head appearing before Clallam Bay (examples; tables 1 through 4). Because all subjects of interest were not part of both studies, tables 5 through 10 refer only to Clallam Bay. Tables 11 and 12 each include data from both studies. In tables 13 through 22, net, live stand statistics were given by age for five units of measure, first for Cascade Head, then following in parallel order, for Clallam Bay. Next were stand increment statistics in four units of measure first for Cascade Head, then for Clallam Bay (tables 23 through 30). The final two tables (31 and 32) give stem distributions for each study.

Figure placement follows a similar logic. figures 1 through 4 give location and plot size statistics for both studies. Figures 5 through 15 illustrate various increment patterns. Figure sequence number places the same units of measure adjacent to each other for the two studies.

Tree Height

Tree height measurements, from a specifically defined sample, were used (1) as a basis to estimate the volume of all trees on the plot, and (2) as a descriptive and numerical plot variable.

We measured trees for total height every 3 to 5 years and for diameter more frequently—annually in the early years of the studies.

Volume Sample

To estimate volume, we chose a sample of at least nine trees whose heights and diameters represented the total diameter range of each plot. We computed plot volume with the tarif system (Brackett 1973, Turnbull and Hoyer 1965, Turnbull and others 1980.) In the tarif system the average tarif number of the sample trees represents the plot and identifies a specific volume-to-basal-area regression line for each plot.

We calculated average plot tarif numbers and examined averages by analysis of variance. We combined average tarif numbers by treatment and smoothed trends by year when tarif numbers were not significantly different. This procedure minimized fluctuations in volume relationships among treatments. It also permitted assigning the correct volume to trees in years when tree heights were not measured. Also, significant differences in average tarif numbers directly describe fundamental relationships among treatments and plots (Hoyer 1985). Average tarif number is a direct index to differences among plot and treatment volumes. Knowing these differences helped to interpret results. Variation among average tarif numbers can also indicate an inadequate number of sample trees or errors in measurements.

The standard volume equation used in this study was developed by Wiley and others (1978):

$$\begin{aligned} \text{Ln CVTS} = & -6.3054647 + 2.0337286(\text{Ln DBH}) \\ & + 1.0849(\text{Ln H}) - 0.014978752(\text{DBH}) ; \end{aligned}$$

where: DBH is diameter outside bark in inches at 4.5 feet above ground,
H is tree height in feet,
CVTS is total cubic foot volume including top and stump, and
Ln is logarithm to base e.

There was no need to use the revision of this equation, devised by Chambers and Foltz (1979), to improve accuracy at the large diameters as our trees were relatively small.

Height as a Plot Variable

The second major use of tree heights is either directly or indirectly as a plot variable. A specifically defined selection of trees and their heights is commonly the basis of site index estimation. We used the method of Wiley (1978) that defines site index as the height of the average tree at age 50 breast height for a sample of the 10 largest diameter trees from a contiguous group of 50. We selected representative trees for site index samples early in the studies and reselected later if trees no longer qualified.

We also desired a direct plot height statistic to be used as a variable in analysis. That statistic can be defined in any of several ways, usually as some segment of the tree diameter range. In this study we examined the average height of a select number of the site index trees (HT 1), the average height of the 40 largest diameter trees per acre (HT 40L, the so-called top height in European forestry), and in successive trials, the average height of the largest 20, 25, and 30 percent of the tree diameter range. The height of the largest 30 percent of the diameter range (HT 30P) had nearly the same values as HT 1, and was the most useful as a plot variable.

For most of the samples examined, a specific selection of trees at one time did not always remain a valid representation after the trees grew. Selecting the most stable portion of the stand diameter range to define the plot height statistic was an important part of preliminary analysis. Precise definition of sample tree selection varied slightly on the two studies. Details appear later.

Our use of the height of the 40 largest trees per acre, the largest 30 percent of the trees on a plot, or other similarly defined parts of the plot diameter range introduced another factor into height estimation. At most, only nine trees were measured for height on a plot. All diameter classes were not represented by a sample tree on each plot. In many years, there were no tree height measurements at all.

We directly assigned a smoothed tree height to every tree on each plot at each measurement by using the calculated volume relationship for the plot. From our volume computation procedure described earlier, we had a volume estimate for each tree. We altered the terms of the standard volume equation (Wiley and others 1978), solved for height, and assigned this height to each tree. We followed this procedure for all average height estimates except the average height of the site index trees for which we used measured sample trees. These results are summarized in tables 3 and 4.

Table 3—Average heights (HT), [1/] tarif number (T), [2/] and representative site index, [3/] by treatment, plot number, total stand age, and year of measurement, Cascade Head, Oregon

Treatment and plot number	12 years, 1963				17 years, 1968		20 years, 1971		25 years, 1976			29 years, 1980				Site index 1980, 29 years 4/
	T	HT 1 4/	HT 40L	HT 30P	T	HT 30P	T	HT 30P	T	HT 1 4/	HT 30P	T	HT 1 4/	HT 40L	HT 30P	
								Feet								
Control:																
923	21.2	30.8a	42.1	31.4	26.0	47.9	28.8	56.4	32.7	67.7a	70.7	34.5	75.9a	81.6	76.9	122a
8-foot spacing:																
915		24.8	29.1	23.6		34.7		43.2		58.6	58.2		70.9	74.5	71.1	114
916		23.6	30.9	24.4		36.8		44.9		54.6	60.4		66.0	77.9	74.8	104
Average	19.6	24.1b	30.0	24.0	17.8	35.8	20.2	44.1	25.6	56.6b	59.3	30.9	68.5b	76.2	73.0	109b
12-foot spacing:																
917		25.6	30.1	26.1		34.2		43.7		57.1	57.7		67.8	69.9	69.3	112
918		25.4	26.7	24.7		35.2		43.9		56.0	58.5		67.7	71.3	70.2	"
Average	19.6	25.5b	28.4	25.4	16.6	34.7	19.0	43.8	23.6	56.5b	58.1	27.5	67.8b	70.6	69.8	114b
16-foot spacing:																
919		23.4	23.2	21.9		33.2		41.0		53.1	55.6		65.5	68.3	67.9	111
920		24.2	26.2	25.0		34.2		42.0		57.8	57.0		65.1	69.8	69.8	107
Average	18.3	23.8b	24.7	23.5	15.7	33.7	17.7	41.5	22.4	55.4b	56.3	26.6	65.3b	69.0	68.9	109b
20-foot spacing:																
921		24.2	20.0	20.6		31.3		38.7		53.8	53.7		65.7	64.8	65.1	109
922		21.0	20.0	20.5		31.7		38.5		50.8	52.9		61.8	63.1	64.1	103
Average	18.3	22.6c	20.0	20.6	15.0	31.5	16.7	38.6	21.4	52.3b	53.3	24.9	63.7c	63.9	64.6	106c

1/ HT 1 is from a sample of 5 largest diameter (2.4 inches) trees on each plot in 1963 and the 5 largest diameter trees on each plot in 1976 and 1980. HT 40L is the average height of the 40 largest diameter trees per acre, and HT 30P is average height of the trees in a plot that make up the top 30 percent of the diameter distribution. HT 40L and HT 30P are computed by solution of the standard volume equation, with diameter known and volume assigned by the described system.

2/ Average treatment tarif numbers (T) are the results of an analysis of variance that show significant (P=0.05) differences by year, treatment, and treatment within year.

3/ Site index is the 50-year base by Wiley (1978).

4/ Mean heights and site indexes for each given age were tested by the Duncan multiple range test. Means with the same letter were not significantly different using 0.05 probability level.

Table 4—Average heights (HT),[1/] tarif number (T),[2/] and representative site index,[3/] by treatment, plot number, and total stand age and year of measurement, Clallam Bay, Washington

Treatment and plot number	11 years, 1971				12 years, 1972		17 years, 1977				20 years, 1980				Site index 1981, 21 years [4/]
	T	HT 1 [4/]	HT 40L	HT 30P	T	HT 30P	T	HT 1 [4/]	HT 40L	HT 30P	T	HT 1 [4/]	HT 40L	HT 30P	
	Feet														
4-foot spacing:															
335		20.4	21.7	20.0		23.2		38.2	42.4	38.6		47.6	53.0	47.2	121
350		19.6	24.1	20.0		21.8		38.3	43.8	38.4		47.7	53.3	47.7	121
Average	20.0	20.0a	22.9	20.0	20.2	22.5	22.8	38.2a	43.1	38.5	26.3	47.6b	53.2	47.5	121b
7.4-foot spacing:															
331		20.3	26.6	22.3		25.9		39.3	43.0	41.0		51.2	52.7	50.5	133
332		18.5	25.9	21.0		25.2		39.8	42.7	40.3		51.7	52.3	49.8	130
342		19.4	25.2	21.0		24.6		36.7	43.0	40.7		50.3	53.0	50.2	128
343		19.4	24.4	21.0		24.4		38.1	41.9	40.2		48.2	51.8	49.8	123
Average	19.1	19.4a	25.5	21.3	19.2	25.0	19.9	38.4a	42.6	40.6	23.1	50.3a	52.3	50.1	129a
9.2-foot spacing:															
333		18.9	22.3	19.3		22.4		35.8	40.1	37.7		45.8	48.9	47.4	119
334		19.4	25.6	21.0		24.3		38.1	40.5	38.8		47.7	49.8	48.3	125
Average	19.1	19.1a	24.0	20.2	19.1	23.4	18.6	36.8a	40.3	38.1	21.5	46.7b	49.3	47.9	122b
12.3-foot spacing:															
336		18.5	19.2	18.7		22.2		36.4	38.0	37.5		44.7	48.5	48.1	121
337		19.5	20.6	19.8		23.7		35.9	38.1	37.8		46.8	48.8	48.5	125
346		20.8	20.1	19.3		23.0		38.0	38.3	37.7		47.9	49.1	48.3	125
347		19.8	19.8	19.5		23.0		38.3	37.2	36.9		46.3	47.6	47.3	123
348		19.1	20.0	19.3		23.3		37.0	38.0	37.6		48.4	48.4	48.0	126
349		18.6	21.8	20.5		24.4		35.8	38.0	37.5		48.0	48.1	47.7	122
Average	19.1	19.2a	20.2	19.9	19.1	23.3	17.8	36.7a	37.9	37.5	20.9	47.0b	48.4	48.0	124b
17.6-foot spacing:															
338		17.9	19.4	19.4		23.3		37.0	38.2	38.2		47.1	47.0	47.0	124
339		20.3	19.9	19.9		23.5		39.6	38.0	38.0		46.4	46.1	46.8	123
Average	19.0	19.0a	19.6	19.7	19.0	23.4	17.8	38.2a	38.1	38.1	19.9	46.8b	46.5	46.9	124b
21.8-foot spacing:															
340		18.8	18.8	19.2		22.6		37.5	36.5	37.0		46.9	45.1	45.5	122
341		18.8	18.8	19.2		22.4		33.8	35.7	36.3		44.0	44.4	45.0	118
Average	18.7	18.8a	18.8	19.2	18.7	22.5	17.1	36.0a	36.1	37.7	19.3	45.4c	44.7	45.3	121b
Grand average															124

1/ HT 1 is height of carefully defined 5 largest trees per plot derived from sample tree measurements. Treatment averages were weighted according to number of trees per plot. HT 40L is height of the 40 largest diameter trees per acre, and HT 30P is the average height of the trees in a plot that made up the top 30 percent of the diameter distribution. HT 40L and HT 30P are computed by solution of the standard volume equation, with diameter known and volume assigned by the described system.

2/ Average treatment tarif numbers (T) are the results of an analysis of variance that showed significant (P=0.05) differences, by year, treatment, and treatment within a year.

3/ Site index is the 50-year base for western hemlock by Wiley (1978).

4/ Mean heights and site indexes for each given age were tested by the Duncan multiple range test. Means with the same letter were not significantly different using 0.05 probability level.

Cascade Head: Plot Design

Each plot at Cascade Head was thought of as a core of 25 study trees, a 5- by 5-tree square. Because of the stand irregularity the number of core trees actually ranged from 25 to 30 on the treated plots. In addition, there was at least one row of designated buffer trees surrounding the 25-tree core. This resulted in a 7- by 7-tree square block or 49 total trees including the buffer. The core trees were numbered and remeasured. This procedure created an isolation strip of approximately 30 feet between plots. The core trees were selected by first marking the exact spot required to meet the nominal spacing, then, for the 8-foot spacing, the largest tree within 2 feet of the ideal marked spot was accepted.

A similar procedure was followed in the 12-foot and wider spacings, except that a 4-foot-radius circle was allowed around the ideal spot. If there were no trees in these circles, the closest tree to the ideal spot was taken. Within these specifications, all locations had a tree at the start of the experiment.

Acreage assigned to each plot included the core trees plus half of the distance between the outside core tree and the next buffer tree in the nominal spacing. Because of variation in the nominal spacing, shapes of some plots were slightly rectangular rather than perfect squares. The acreage assigned to each plot therefore varied between two plots that were otherwise identical. Plot acreage and other basic plot statistics appear in table 12 in the appendix.

Cascade Head: Plot and Tree Measurements

Forest Service scientists tagged the core trees with an aluminum nail and a tree number at 4.5 feet above the ground and measured each tree for diameter and height when plots were installed. They measured trees annually for diameter and periodically for tree height in the first 15 years following installation, then measured again after a 4-year interval. In 1978, the four largest diameter trees on each plot were identified for site index measurements. In 1979, these trees were measured for height to the base of the live crown (the lowest main whorl with live branches on all four sides of the tree). This was the basis for estimating live crown ratios. In 1980, we selected six trees from the upper half of the diameter range and three from the lower half for volume assessment. When possible, we used the same trees for both site index and volume estimation.

We computed average tarif number and smoothed the trends with time, as described earlier. Average tarif numbers for selected years appear in table 3.

We selected the five largest diameter trees in the 1- to 3-inch-diameter classes on each plot in 1963 and the five largest diameter trees per plot in 1980 to represent plot height.

Clallam Bay: Plot Design

Like the Cascade Head study, plots at Clallam Bay were conceived as a core of 25 trees (with a buffer) that would be available in the future at times of critical measurement to characterize plot treatment. For plots where later thinning was planned, we selected more trees initially so there would be 25 core trees following planned thinnings. Consequently, plots selected for subsequent thinning were larger than the plots thinned at the start of the experiment. Although the design specified the plot core as squares, we used rectangles and some other geometric shapes to accommodate the limitations of the study area and still maintain required core trees within adequate buffer zones. The acreage was assigned to each plot following the procedure explained for the Cascade Head plots. Actual plot acreage is listed for each plot in table 12 in the appendix.

Two years before treatment began, we thinned the whole area, except for the nonthinned control plots, to approximately a 4-foot spacing. We increased stand uniformity by removing both very small and very large trees that were more than 2 years younger or older than the average age of the leave trees. The average leave trees were approximately 2 inches in diameter. We established some temporary plots following this calibration thinning to determine if the removal of trees over 2 inches had any effect on diameter growth of leave trees. After 2 years there was no apparent effect on leave trees; all were growing at a rate consistent with their diameter. We concluded that the 2-year period was sufficient to stabilize the stand and make all plots as uniform as possible. We then randomly selected locations for treatments, established the plots, and thinned.

We selected trees to remain on plots at the following basal area levels: 1.6, 2.5, 5, 8, and 15 square feet. The spaced control plots had 38 square feet per acre. In addition, we considered spacing and general tree vigor in balance with the target basal area. Total plot basal area was kept within 3 percent of the target basal area level prescribed in the study plan. Prior to thinning, the mean diameter of any given plot also had to be within 0.1 inch of the mean of all plots. The problem of tree selection was more difficult than it might have been because of damage by mountain beaver (*Aplodontia rufa*) to the bases of the trees. We attempted to select leave trees that had little or no basal scaring from mountain beaver. (The scope of the mountain beaver problem is reported by Hoyer and others (1979).)

Clallam Bay: Plot and Tree Measurements

We tagged the core trees with an aluminum nail and a tree number at 4.5 feet above ground and measured each tree for diameter. We selected nine volume sample trees across the range of the diameters on each plot and measured heights periodically. When the stand was older we also sampled for site index on each plot.

We anticipated a form change as a result of the various treatments and foresaw the need for a more precise volume estimating procedure that would include a measure of tree form as well as of height and diameter. We used the nine trees selected for volume sampling on representative plots and measured tree form. (We lacked these data for the Cascade Head study.) Measurements, a modification of the Hohenadl procedure (Assmann 1970, Hoyer 1985), were made of stem diameters at points on the stem proportional to total tree height. Subsequently, tree volume equations were developed that used any of several form quotients based on measurements taken at these points (Hoyer 1985). In 1983, tree form quotients were estimated on 12 to 15 trees on each plot using a wide-angle Spiegelrelaskop[1/] at diameter at breast height and points D.9, D.7, and D.5: these are, respectively, outside bark diameters at 90, 70, and 50 percent of the total tree height measured from the tip down.

Treatment changed tree stem form (Hoyer 1985), but the change did not influence the cubic-foot volume increment appreciably. To keep the two studies on the same basis, volume equations in subsequent analyses will disregard the influence of tree stem form change brought about by treatment. The exception to this is in the section discussing the study of tree form. The tarif system used for computing the volume of sample trees and plots was described earlier. Representative average tarif numbers appear in table 4.

[1/] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

We selected the seven largest trees per plot in 1971 and used the same trees again in 1977 to represent mean height, except for two trees that graphic analyses showed to be unusually larger in diameter than others in the study. Including them would have seriously inflated the height estimate for two plots. The results appear in table 4 and are identified as HT 1. In 1980, with the benefit of additional height sample trees, we calculated the height of the eight largest diameter trees per plot. These are also referred to as HT 1 in table 4.

We used four sample trees on each plot as a basis for site index estimates in 1971. We also felled and sectioned four site index trees in an adjacent, unlogged, 90-year-old stand. These together with plot site index trees gave a more meaningful pattern of height growth than did the young site index trees alone (Hoyer 1983).

In 1980, we selected up to 16 trees on each plot to update height measurements. Four of the trees on each plot qualified for site index sample trees; the others were used for tree volume (tarif) and tree form measurements.

We used the four site index sample trees as a basis for estimating the height to base of live crown and crown widths in 1980. Base of live crown was defined the same as for the Cascade Head plots and was the basis for estimating live crown ratios. Crown widths were an average of two crown diameters taken at right angles to each other from the vertical drip line of the widest branch tips. Crown width, live crown ratios, limb characteristics and characteristics of lesser vegetation were summarized (table 5) for the major early thinning treatments.

Clallam Bay: Late Competition Thinning Plots

Following the growing season in 1977, at stand age 17, we thinned two plots that had been growing at 4.0-foot spacing and two that had been growing at 7.4-foot spacing. In each case, the mean diameter of the trees following thinning was the same as the mean diameter before thinning. By 1977 the 4.0-foot spacing treatments had reached 162 square feet of basal area per acre and the 7.4-foot spacing had reached 110 square feet per acre. Both treatments had passed the culmination of current annual basal area increment.

For each treatment we chose a target basal area after thinning of 73 square feet per acre, the level that had been reached by the 9.2-foot early thinning treatment. The number of stems per acre after late thinning varied among treatments. Actual basal area attained after late thinning was 75.8 and 72.1 square feet per acre (table 20).

We selected one 0.01-acre plot in the absolute control stand (that had not received any preparatory thinning at the start of the study) and thinned it to the level of basal area attained by the early thinning to 12.3-foot spacing; that is, from 242 to 52 square feet per acre.

Thinning to the specified target basal areas allowed several interesting comparisons Because of similar after-thinning basal area, the late competition thinnings at 4 0- and 7.4-foot spacings become directly comparable with the earlier crown-closure thinning spaced at 9.2 feet. Similarly the thinned absolute control becomes comparable with the earlier crown-closure thinning spaced at 12.3 feet.

Table 5–Evaluation of understory, by treatment and plot, with spacing and mortality (per acre), Clallam Bay, Washington

Treatment and plot	1977, ground cover	1977, limbs on bole	1980, live crown ratio	Crown widths	Number of stems		Spacing, 1971	Mortality, 1971-80	
					1971	1980		Total	Per year
				Feet			Feet	Number of trees	
Nonspaced control	--	--	0.46	--	3,437*	5,021	3.5*	No mortality; 1,584 ingrowth for 12 years.	
4.0-foot spacing, plots 335 and 350	Nothing except western hemlock seedlings and mushrooms. Scattered oxalis 1/ occurs on plot edge from side light.	Laterals often dead 6-10 feet up. Multiple overlapping layers of side branches.	.51	11	2,731	2,382	4.0	349	39
7.4-foot spacing, plots 331, 332, 342, and 343	Scattered oxalis 1/ occurs in openings.	Needles gone from interior part of lowest branches. Considerable branch overlap.	.70	--	798	729	7.4	69	7.6
9.2-foot spacing, plots 333 and 334	Deer-fern prominent; oxalis, salmonberry common. 1/	Needles to bole on lowest branches. Open sky between trees. Some branch overlap.	.78	19	513	449	9.2	14	1.5
12.3-foot spacing; plots 336, 337, 346, 347, 348, and 349	Common occurrence of annuals and perennials.	Limbs and needles to ground.	.77	22	287	263	12.3	24	2.7
17.6-foot spacing, plots 338 and 339	Same.	Same.	.80	22	140	131	17.6	9	1.0
21.8-foot spacing	Same.	Same.	.84	22	91	83	21.8	8	0.9

* = 1969 instead of 1971; -- = measurements not made.

1/ Oxalis is Oxalis oregana Nutt. ex T. and G.; deer-fern is Blechnum spicant (L.) Roth.; and salmonberry is Rubus spectabilis Pursh.

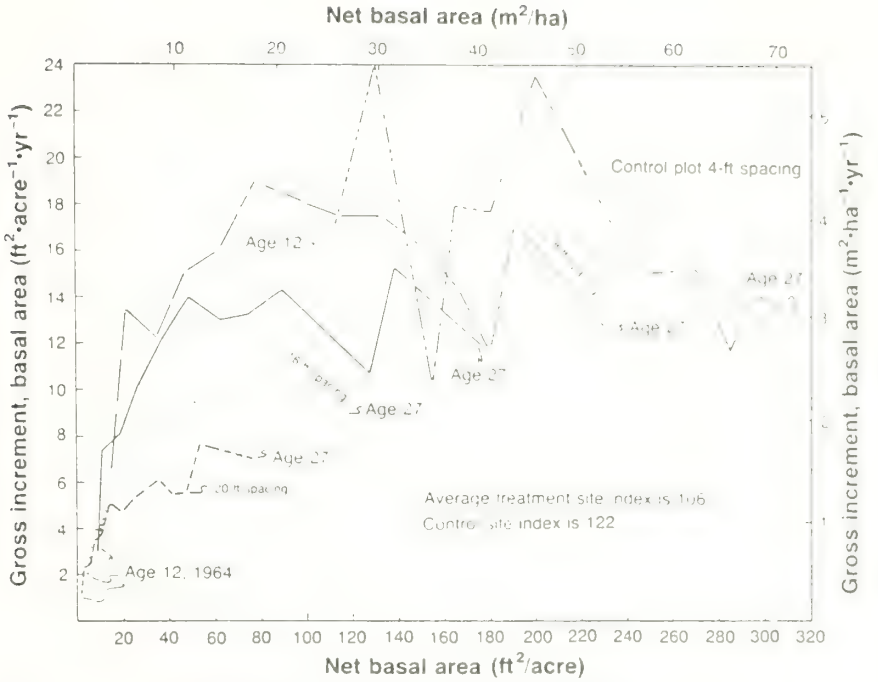
Net basal area (m²/ha)
Gross increment, basal area (ft²·acre⁻¹·yr⁻¹)
Gross increment, basal area (m²·ha⁻¹·yr⁻¹)
Net basal area (ft²/acre)
Control plot 4-ft spacing
Age 12
Age 27
Age 12, 1964
Average treatment site index is 106
Control site index is 122

Figure 5.—Gross annual basal area increment, by level of basal area, for spacing treatments at Cascade Head.

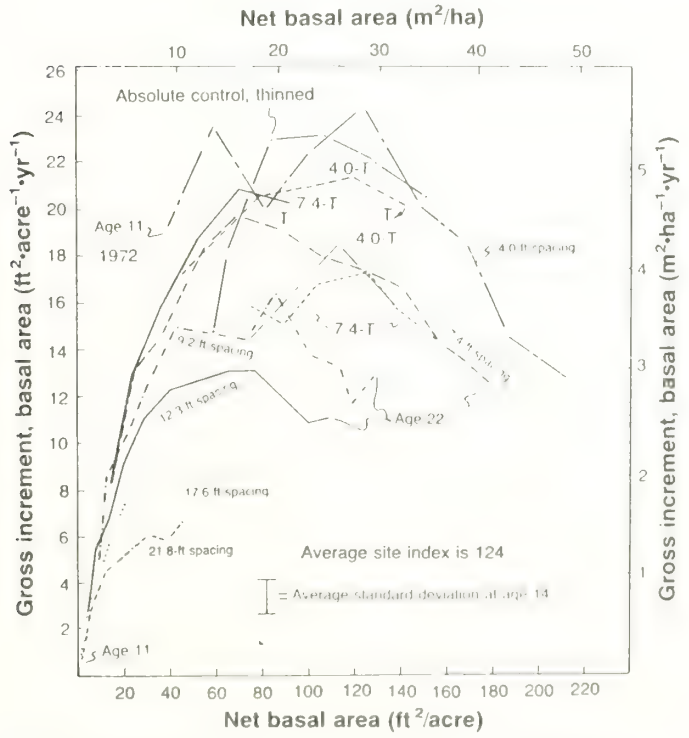

Figure 6.—Gross annual basal area increment, by level of basal area, for early and late spacing treatments at Clallam Bay.

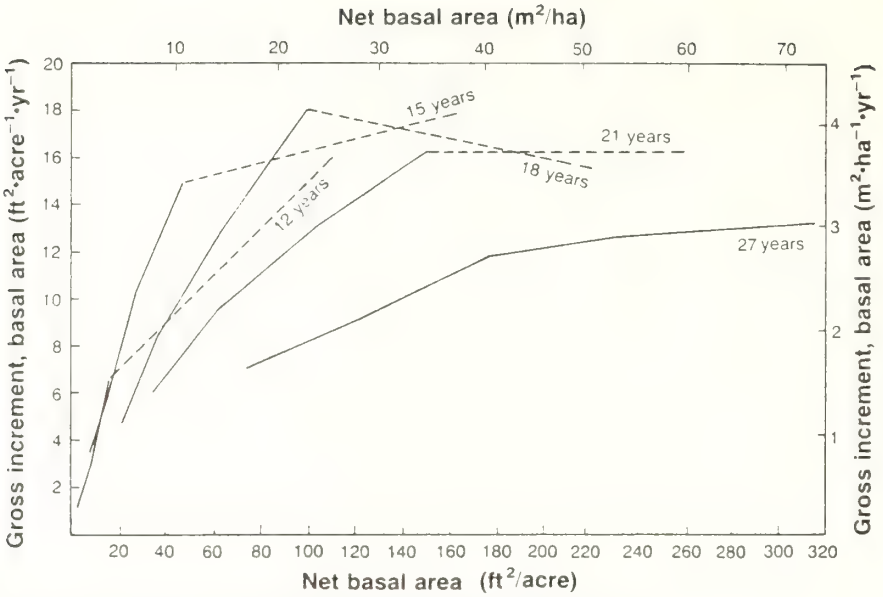
Net basal area (m²/ha)
10 20 30 40 50 60 70
Gross increment, basal area (ft²·acre⁻¹·yr⁻¹)
20 18 16 14 12 10 8 6 4 2
Gross increment, basal area (m²·ha⁻¹·yr⁻¹)
4 3 2 1
15 years
21 years
18 years
12 years
27 years
20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320
Net basal area (ft²/acre)

Figure 7.—Gross annual basal area increment, by level of basal area and age, for combined treatments and control plot at Cascade Head.

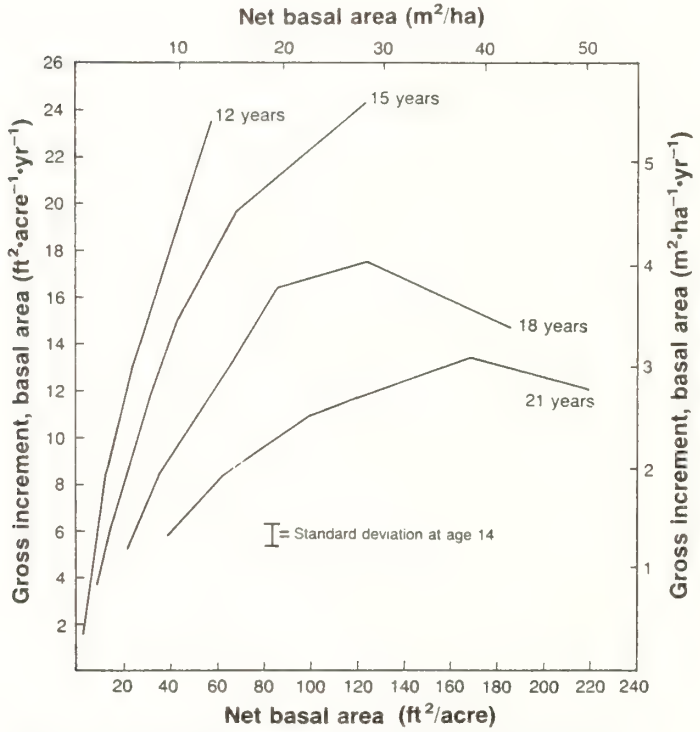
Net basal area (m²/ha)
10 20 30 40 50
Gross increment, basal area (ft²·acre⁻¹·yr⁻¹)
26 24 22 20 18 16 14 12 10 8 6 4 2
Gross increment, basal area (m²·ha⁻¹·yr⁻¹)
5 4 3 2 1
12 years
15 years
18 years
21 years
I= Standard deviation at age 14
20 40 60 80 100 120 140 160 180 200 220 240
Net basal area (ft²/acre)

Figure 8.—Gross annual basal area increment, by level of basal area and age, for combined treatments and controls at Clallam Bay.

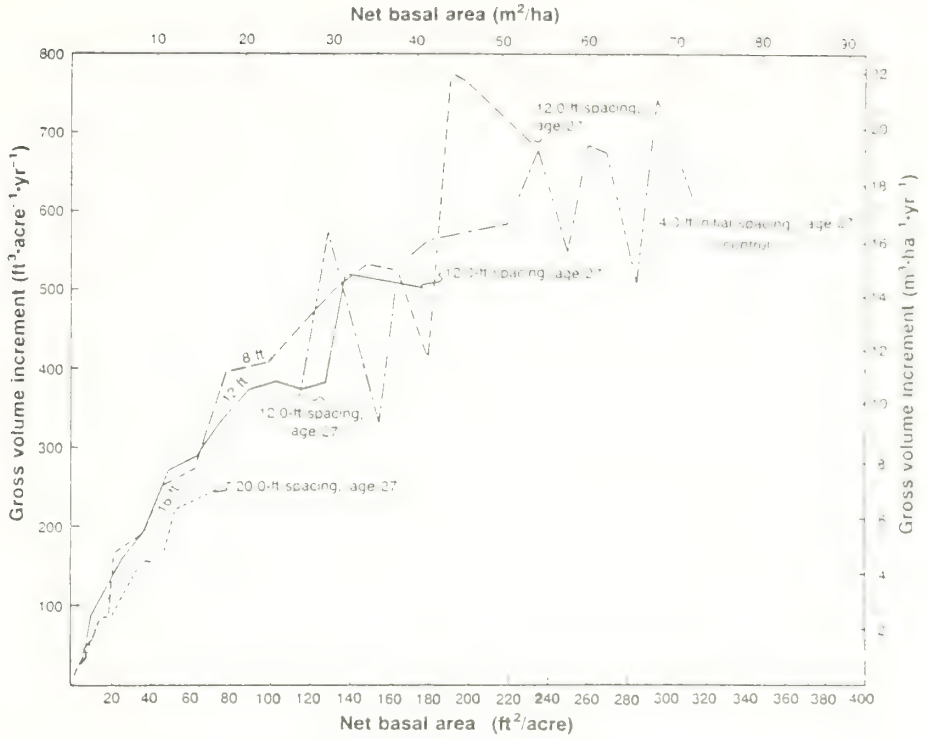

Figure 9.—Gross annual cubic-foot volume increment, by level of basal area, for spacing treatments at Cascade Head.

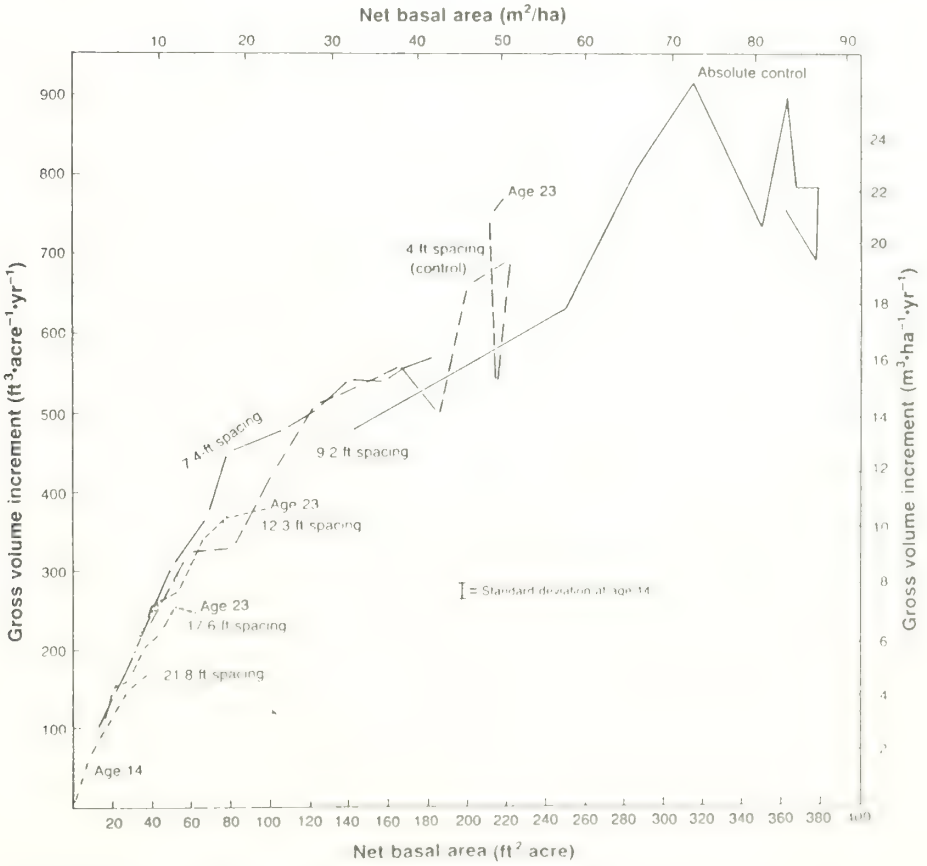

Figure 10.—Gross annual cubic-foot volume increment, by level of basal area, for spacing treatments at Clallam Bay.

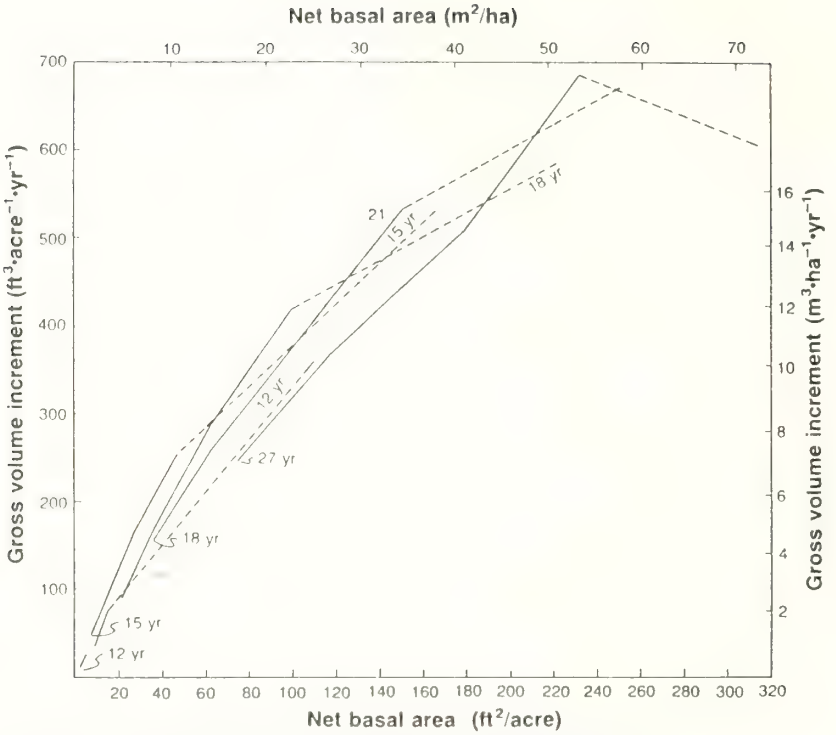

Figure 11.—Gross annual cubic-foot volume increment for combined treatments and control, by level of basal area and age, at Cascade Head.

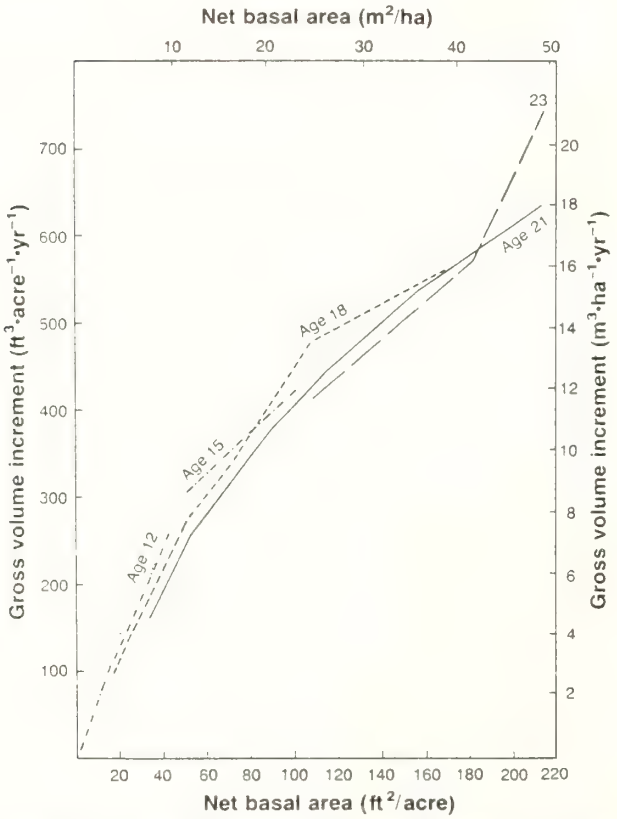
Net basal area (m²/ha)
10 20 30 40 50
Gross volume increment (ft³·acre⁻¹·yr⁻¹)
700 600 500 400 300 200 100
Gross volume increment (m³·ha⁻¹·yr⁻¹)
20 18 16 14 12 10 8 6 4 2
23
Age 21
Age 18
Age 15
Age 12
20 40 60 80 100 120 140 160 180 200 220
Net basal area (ft²/acre)

Figure 12.—Gross annual cubic-foot volume increment for combined treatments and controls, by level of basal area and age at Clallam Bay.

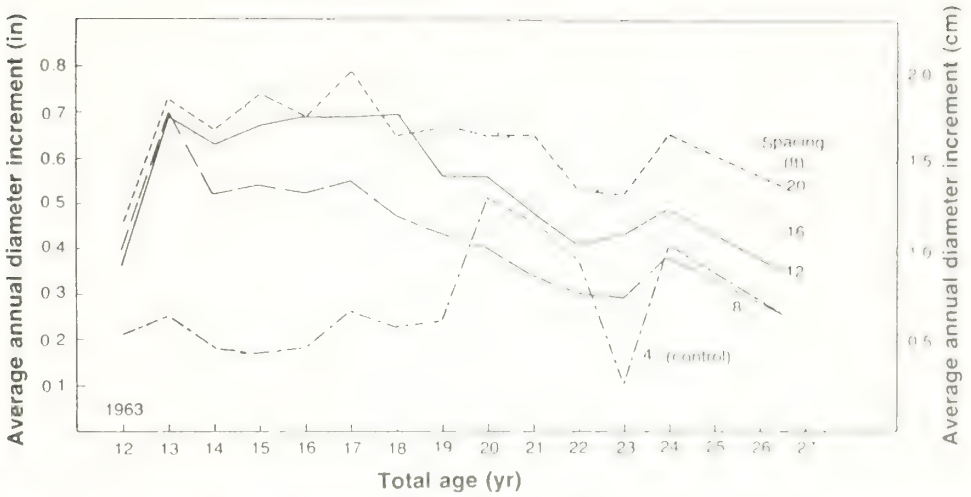

Figure 13.—Average diameter increment, by year, for spacing treatments at Cascade Head.

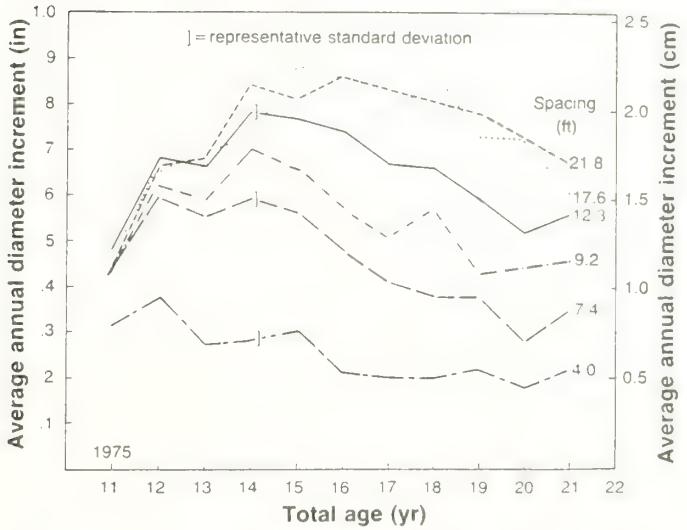

Figure 14.—Average diameter increment, by year, for spacing treatments at Clallam Bay.

Results

Results are summarized separately for the two study areas.

Cascade Head: Tarif Number, Height, and Site Index

Average plot tarif numbers differed significantly by treatments and across time according to analysis of variance tests. At the start of the experiment in 1963, the average tarif number of the 8- and 12-foot spacing treatments was 19.6; the control plot was 21.2. Differences in average tarif became more apparent in the years following study establishment; closely spaced stands developed a higher average tarif number than more widely spaced stands. This meant that there was a fundamentally different tree-volume-to-diameter relationship for the different spacings.

The average height of the five largest diameter trees on the plot (that is, the site index trees) appear as HT 1 in table 3. HT 1 differed among treatments in 1963. HT 1 of the control plots at 30.8 feet was 5 or more feet taller than the height of trees in the other treatments.

The 22.6-foot height of the widest spacing was significantly shorter than the average height of the other spaced treatments. Similar differences, significant at the 0.05 level by the Duncan multiple range test (Steel and Torrie 1980), occurred in 1976 and in 1980, the two other times when sufficient site index sample tree measurements had been made (table 3).

The average height of the 40 largest trees per acre (HT 40L) (see table 3) may be directly compared with the height of the site trees. The number of sample trees that represented the 40 largest per acre ranged from one to four within a plot, depending on plot area and spacing. The height of the 40 largest trees per acre was consistently taller on closely spaced stands than on widely spaced stands. This was true in 1963 at establishment and remained true in later years. The heights of the 40 largest trees exceeded height of the site trees by as much as 11 feet for some treatments. In other cases, HT 40L was as much as 2 to 3 feet shorter than the height of the site trees.

Height of the largest 30 percent of the plot diameter (HR 30P in table 3) behaved generally the same way as the other height estimators. HT 30P was, however, consistently closer to values of HT 1 than was the average height of the 40 largest trees.

Site index estimated by plot in 1980 at total age 29 appears in table 3. As noted earlier, site index of the control plot was significantly higher at 122 than the average of the treated plots at 109 (based on Duncan multiple range test at the 0.05 level of probability). Differences in site index among the four spacings were not statistically significant.

Cascade Head: Yields and Increment

We summarize plot height, diameter, volume, live crown ratio, and other descriptive yield statistics in table 1. Detailed plot and treatment statistics appear for seven representative stand ages in tables 13 through 17 in the appendix. Increment statistics for the same representative ages appear in tables 23 through 26 in the appendix. Average trends of basal area and volume increment appear in figures 5, 7, 9, and 11 for spacing treatment by age and level of basal area. Trends of average annual diameter increment are in figure 13. To make comparisons easy, figures for Cascade Head (odd numbers) were placed adjacent to those with the same unit of measure for Clallam Bay (even figure numbers).

Clallam Bay: Tarif Number, Height, and Site Index

Average heights of trees for Clallam Bay appear by plot and treatment in table 4. The effects of treatment on the various height estimators were similar to those for the Cascade Head Plots. The mean tarif number was significantly higher on closely spaced plots as compared to widely spaced plots.

HT 1, the height of the selected largest site index trees, was not significantly different among treatments through 1977. In 1980, the difference became statistically significant The average height of site index trees, by treatment, for the plots at 7.4-foot spacing was highest at 50.3 feet compared with 47.6 for the 4-foot spacing and 45.4 for the 21.8-foot spacing. Average height of the site index trees for the widest spaced treatment was shorter than the average for the medium-spaced treatments, and the heights of site index trees on the 7.4-foot spacing was taller than those of the medium treatments. The height of site index trees on the 7.4-foot spacing was taller because, by chance, three of the plots had higher site indices than the average for the remainder of the treatments The shortness of the trees in the 21.8-foot spacing was apparently not directly related to a treatment difference.

The height of the 40 largest trees per acre at Clallam Bay behaved similarly to HT 40L on the Cascade Head plots. Estimates of height for widely spaced trees were almost the same as the heights for the site index sample trees. For closely spaced trees, HT 40L exceeded the height of the site index sample trees. This was consistently true at all ages.

Height of the largest 30 percent of the trees on each plot conformed more closely to the height of the site index sample trees at the Clallam Bay plots than it did to those at the Cascade Head plots. There was no apparent relationship between height of the largest 30 percent and spacing at the Clallam Bay plots.

We examined site index on each plot in 1981. We carefully selected the eight largest diameter trees from a group of 50 contiguous trees using both plot trees and qualifying buffer zone trees. We also had estimated the site index in 1971 when the trees were only age 6 breast height. The 1971 sample, 28 trees from seven representative plots, averaged site index 129. The overall average in 1981 was 124, an apparent drop of 5 points of site index.

We examined the 1981 site index estimates (table 4) by analysis of variance and found a significant difference by the Duncan multiple range test. The differences in site index were apparently not related to spacing. The highest indices, at or near 130, were on three plots in the 7.4-foot spacing. Site indices on plots with the widest and the closest spacing were the same.

Clallam Bay: Yields and Increment

Summarized plot height, diameter, live crown ratios, and other descriptive yield statistics appear in table 2 for all treatments at age 11 (the beginning of the study) and for selected later ages. Detailed plot and treatment statistics appear in tables 18 through 22 (in the appendix) for six representative ages. Increment statistics for the same ages appear in tables 27 through 30 in the appendix.

Average trends of basal area and volume increment appear in figures 6, 8, 10, and 12 for spacing treatments by age and levels of basal area. Trends of average annual diameter increment by age and treatment spacing appear in figure 14.

Clallam Bay: Ingrowth

Ingrowth became obvious in the widely spaced treatments a few years after initial spacing. We did not measure ingrowth those years but began in 1977 at the Clallam Bay study. A summary of ingrowth since 1977 appears in table 6.

The effect of ingrowth is most striking on the two widest spaced treatments. By 1982, the number of ingrowth trees exceeded the number of trees left on the plots after original treatment and cubic-foot volume per acre of ingrowth on the 17.6-foot spacing was 19 percent of the volume of the study trees. On the 21.3-foot spacing, ingrowth volume was 77 percent of the volume of study trees. Average plot diameter of ingrowth trees in 1982 was 3 inches or less, about one-third the average diameter of original trees on the 17.6- and 21.3-foot spacing.

Mortality

In theory, the widely spaced trees will grow to a closed stand without competition mortality and then, as competition increases, some will die. In fact, however, there has been some continuing tree loss even with wide spacing. The trends of tree mortality are easily seen by tracing the number of stems per acre by year in the appendix tables. At the Cascade Head study, the equivalent of 6.4 trees per acre per year were lost in the 8-foot spacing treatment between 1973 and 1980 (table 13). Trees were in the suppressed diameter classes. The 12-foot spacing treatment lost 1.4 trees per acre per year, the 16-foot spacing treatment lost 0.8, and the 20-foot spacing treatment lost 0.26 in the 17-year period. In contrast, the 3.0-foot spacing has suffered competition mortality since the study began.

The Clallam Bay study treatments have also been losing a few trees each year. Competition mortality began in 1974 in the 4-foot control plots, which lost an average of 145 trees per acre per year in 8 years. The equivalent of this loss in cubic-foot volume is summarized in table 7. Table 7 also shows volume losses by year for the other treatments. Except for the 4.0-foot spacing, none of this loss was from competition. In each case either armillaria root rot (*Armillaria mellea* [Vahl ex Fr.] Kummer) or damage caused by mountain beaver was the primary cause of death.

Mortality influences estimates of stand increment in that either gross or net increment figures can be reported. In conventional use, gross increment is the periodic change of live trees measured at the start of a growth period even if some had died before measurement at the end of the period.

Net values of increment are the result of subtracting from the total increment, the total units of wood (not just the increment of dead trees) that had died during the period. Gross increment seems to have more meaning. In this study both gross and net figures are reported to keep numbers precisely defined. The differences between gross and net were so small that the distinction made little difference to overall trends or to interpretation of results.

Armillaria Root Rot

A summary of the impact of armillaria root rot appears in table 8. Some trees died from the disease in 1978 and others have died since. Individual plots in the 7.4- and 9.2-foot spacings were mostly seriously affected. We don't know why.

Table 6—Net accumulated ingrowth, by spacing treatment and total age, Clallam Bay, Washington [1/]

Treatment	Total age and year					
	17 1977	20 1980	22 1982	17 1977	20 1980	22 1982
Feet	Number of stems per acre			Cubic feet per acre		
4	0	0	0	0	0	0
7.4	94	102	78	37	70	80
9.2	66	95	86	19	49	73
12.3	71	86	87	15	40	56
17.6	230	490	492	41	178	278
21.3	649	1,384	1,370	86	423	712

1/ Some ingrowth occurred before measurements began in 1977. Some treatments reached peak values in years not summarized here. Mean diameter of ingrowth trees ranged from 1.5 to 3 inches for the range of years shown.

Table 7—Annual mortality, by spacing treatment and total age, Clallam Bay, Washington

Treatment	Total age and year											
	11 1971	12 1972	13 1973	14 1974	15 1975	16 1976	17 1977	18 1978	19 1979	20 1980	21 1981	22 1982
Feet	Cubic feet per acre											
4.0	--	--	--	--	--	--	--	2	1	3	114	240
4.0, thinned	--	--	--	--	--	--	1/ 1,279	--	--	--	--	10
7.4	--	--	2	2	--	1	--	12	8	7	49	17
7.4, thinned	--	2	2	--	8	2	1/ 534	31	--	--	--	14
9.2	--	4	3	6	--	--	--	25	18	--	178	8
12.3	--	--	--	1	1	--	--	8	11	4	33	41
17.6	--	--	--	--	1	--	--	--	24	--	--	3
21.3	--	--	--	--	--	--	1	--	--	--	--	--

-- = values less than 1 cubic foot.

1/ Volume removed in planned thinnings.

Table 8—Average number of trees dying from or diseased by armillaria root rot, by spacing treatment and year, Clallam Bay, Washington

Treatment and tree condition	Total age and year: 17 1977	18 1978	19 1979	20 1980	21 1981	22 1982	Number in 1982 as percent of number in 1971
Feet	– – Accumulated number of trees per acre – –						Percent
4.0:							
Dead	--	--	--	29.0	58.0	58.0	2.1
Diseased	--	--	--	--	--	--	--
4.0, thinned:							
Dead	--	--	--	--	--	--	--
Diseased	--	--	--	--	19.0	19.0	0.7
7.4:							
Dead	--	--	--	3.2	21.9	25.4	3.2
Diseased	--	--	--	8.0	20.5	27.2	3.5
7.4, thinned:							
Dead	--	6.0	6.0	12.0	12.0	18.0	2.1
Diseased					6.0	6.0	0.7
9.2:							
Dead	--	8.0	19.5	19.5	27.5	27.5	5.3
Diseased	--	--	--	8.0	19.5	19.5	3.8
12.3:							
Dead	--	1.2	2.4	3.6	6.1	9.4	3.3
Diseased	--	--	--	3.5	9.3	11.6	4.0
17.6:							
Dead	--	--	--	--	--	2.5	1.8
Diseased	--	--	--	2.5	5.0	5.0	3.5
21.3:							
Dead	--	--	--	--	1.5	1.5	1.6
Diseased	--	--	--	1.5	1.5	1.5	1.6

-- = none.

Clallam Bay: Increment of Late Competition Thinning

Increment results appear in tables 28 through 30 in the appendix for late competition thinning treatments and their comparable alternatives. A summary of volume increment expressed as a percent of the increment of the 4.0-foot treatment appears in table 9, and figure 15 shows volume increment trends by year. Early thinning to 9.2 feet and wider spacing produced consistently less volume increment percent than did the 4.0-foot thinned control, the late thinning to 4.0-foot spacing, or the late thinning to 7.4-foot spacing. All the widely spaced early thinnings grew at less than full stocking and the increment was lower than was the increment of more fully stocked stands.

Table 9—Smoothed trends of cubic-foot volume increment percent and relative density [1] for matched early and late thinning-treatments, Clallam Bay, Washington

Treatment	Total age and year								
	16 1976	17 1977	18 1978	19 1979	20 1980	21 1981	22 1982	23 1983	Average, 1978-83
	Percent of control volume increment								
4.0 feet	100 [2] (462)	100 (510)	100 (583)	100 (612)	100 (639)	100 (656)	100 (671)	100 (618)	100
4.0 feet, thinned [3]	100	100	63	71	79	89	88	87	79
7.4 feet	82	86	88	88	87	87	86	86	87
7.4 feet, thinned [3]	82	86	70	76	83	92	91	91	84
9.2 feet	54	59	64	67	72	71	72	73	70
12.3 feet	42	47	52	57	61	60	58	62	58
Absolute control, [4] thinned	--	98	51	71	86	97	106	113	87
	Relative density								
4.0 feet	82.6	91.0	98.0	102.8	106.5	107.0	101.7	97.5	102.2
4.0 feet, thinned	80.0	36.8	39.2	44.0	49.3	55.1	59.8	64.4	52.0
7.4 feet	40.8	47.2	52.8	58.0	62.6	65.8	68.9	71.9	63.3
7.4 feet, thinned	42.2	33.7	36.8	41.0	45.8	50.7	54.7	58.3	47.7
9.2 feet	26.6	31.5	35.4	39.8	43.7	43.9	46.7	49.8	43.2
12.3 feet	17.7	21.6	25.2	28.6	32.1	34.6	36.5	38.8	32.6
Absolute control, thinned	--	--	33.0	39.7	47.7	55.3	62.3	68.6	51.1

1/ Relative density is stand basal area (mean diameter)$^{-.5}$.

2/ Numbers in parentheses are cubic-foot volume increment.

3/ Thinned following the 1977 growing season to the level of basal area of 9.2-foot treatment.

4/ Thinned following the 1977 growing season to the level of basal area of 12.3-foot treatment.

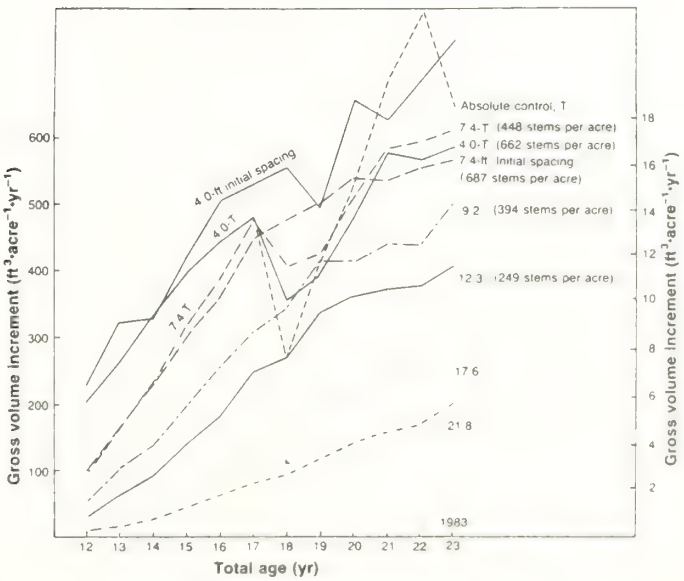

Figure 15.—Trends of volume increment by year for late thinnings (4.0 T, 7.4 T, and absolute control T), matched to the basal area level of early thinnings (9.2, 9.2, and 12.3 spacings), Clallam Bay, Washington.

The year-by-year response patterns were similar in all three late-thinned treatments. Increment response percent averaged 15 percentage points lower in the first 3 years after thinning than in the second 3 years for two of the late thinning treatments. The single absolute control plot that was thinned late also had lower response percentages in the first 3 years than in the last 3, but response in the last 3 years was unusually high and exceeded the rate of response of the 4.0-foot control. Details are in table 9.

Six-year volume increment of the two late-thinned treatments exceeded by 9 and 14 percentage points the increment of the 9.2-foot initial spacing treatment to which they had been matched by basal area level. This remained true both before and after chance differences in mortality among treatments were accounted for. The single thinned absolute control plot exceeded by 29 percentage points the increment of the 12.3-foot initial spacing to which it had been matched by basal area level. (These results, expressed as 79, 84, and 87 percent in table 9, convert to increments of 55, 86, and 180 cubic feet per acre per year of the late-thinned treatments over the early-thinned treatments to which they had been matched by basal area.) These results expressed in terms of volume increment, rather than as percentages, appear in figure 15.

Results in table 9 describe stand treatments in terms of relative density (defined as stand basal area divided by the square root of mean diameter). Relative density of the three late-thinned stands differed from that of the initial spacing stands to which they had been matched by equal basal area levels.

Clallam Bay: Tree Stem Form

Details of the procedure and results for the early years of the form study have been reported (Hoyer 1985). Resulting tree size and volume differences as of 1979 appear by treatment in table 10. Volume estimates use equations with only tree diameter and height in one case and diameter, height, and two form quotients in the other. The form quotients are D.5/D.9 (the ratio of outside bark diameter at half the total tree height, with diameter at nine-tenths of the distance from the tree top down) and D.9/DBH.

Each value for form quotient D.5/D.9 given in table 10 was significantly different from the next wider spacing except for the two widest. Test of significance was by analysis of variance and examination of confidence bands about each group mean using the 0.05 probability level. At the tree height of those sample trees the quotient D.9/DBH was a constant near the value of one and cancelled out of the equation. The data in table 10 clearly show that use of diameter and height alone, without the effect of tree form, overestimated the volume of widely spaced trees.

At the 1983 remeasurement, estimates of form quotients D.7/D.9 and D.9/DBH using the Spiegelrelaskop were significantly related to live number of stems per acre in 1982. Significance of F-value and R^2 were 95 percent and 0.22 for D.7/D.9 and 97.5 percent and 0.31 for D.9/DBH. Trends of D.7/D.9 were clearly higher (0.825) for closely spaced trees and lower (0.79) for open-grown trees. Variation was high. Values of D.9/DBH were 0.984 for closely spaced trees and 0.968 for open-grown trees.

Wood Quality, Both Studies

Number of rings per inch is one indicator of wood quality, as four rings per inch and less is not permitted in structural light framing. The faster growth material is permitted in stud grade material but the difference in price between studs and structural light framing approached $100 per thousand board feet in the 1983 market. We converted average diameter (listed by age and treatment in the appendix tables) into terms of the average number of radial rings per inch of wood (table 11).

Table 10—Volume of a tree of average diameter and height, in 1979, computed both with and without the use of smoothed, average form quotients, by spacing treatments 1/

Treatment	Diameter	Height	Quotient D.9/DBH	Quotient D.5/D.9	Number of samples	Volume without form	Volume using form	Difference
Feet	Inches	Feet				- - Cubic feet - -		Percent
4.0	3.8	42	1.00	0.725	13	1.52	1.53	0
7.4	5.9	42	1.00	.655	12	3.59	3.45	4
9.2	6.4	42	1.00	.592	17	4.21	3.77	11
17.6	7.7	42	1.00	.538	12	6.01	5.10	15
21.8	7.7	42	1.00	.538	21	6.01	5.10	15

1/ Equation without form quotients:

$$\log V = -2.71907 + 2.02478(\log DBH) - 0.0059\ DBH + 1.07716(\log H).$$

Equation with form quotients:

$$\log V = -2.53284 + 2.03622(\log DBH) - 0.0014\ DBH + 1.01277(\log H)$$
$$+1.76285(\log (D.9/DBH)) + 0.36689(\log (D.5/D.9)^2).$$

log = logarithm to base 10. D.9/DBH is the outside bark ratio of diameter at nine-tenths of tree height from tip down, to diameter at breast height. D.5/D.9 is the ratio of outside bark diameter at half height to outside bark diameter at nine-tenths of tree height.

Table 11—Number of radial rings per inch of growth on the average-sized tree, by spacing treatment and total age, Cascade Head, Oregon, and Clallam Bay, Washington

Treatment	Total age 1/ 12	14	17	20	22	27
Feet	- - - - - - - - Number of rings per inch - - - - - -					
Cascade Head:						
3.0 control	9.5	5.4	7.7	3.9	5.4	7.6
			average diameter under 6 inches			
				average diameter over 6 inches		
8.0	5.0	3.8	3.6	5.0	6.7	7.6
12.0	5.5	3.1	3.0	3.6	4.6	5.8
16.0	4.2	3.3	2.4	3.0	3.6	4.6
20.0	4.5	3.0	2.5	3.1	3.8	3.7
Clallam Bay:						
4.0 control	5.5	7.1	9.7	10.0	4.2	
						average diameter
4.0, thinned	6.7	7.4	2/ 4.8	4.7	5.6	under 6 inches
7.4	4.3	3.5	4.5	6.1	6.3	
						average diameter
7.4, thinned	4.5	3.5	2/ 3.9	4.1	4.4	over 6 inches
9.2	4.9	3.1	3.7	4.5	3.8	
12.3	4.2	2.8	2.8	3.6	4.2	
17.6	4.3	2.9	2.5	2.8	3.0	
21.8	4.5	2.6	2.4	2.6	2.9	

1/ Age for Clallam Bay is 11.

2/ Thinned in 1977; results only for a 1-year increase.

Live Crown Ratio, Both Studies

Live crown ratio, measured at age 28 for Cascade Head and at age 20 for Clallam Bay, appears for each initial spacing treatment in tables 1 and 2. At Cascade Head the live crown was 52 percent of total tree height on the 8-foot spacing and increased to 76 percent on the 20-foot spacing. At Clallam Bay, the 7.4-foot spacing had 70 percent live crown; the 21.8-foot spacing had 84 percent live crown.

Discussion

Site-Tree Height

Differences in spacing did not influence height of the site index tree on the plots. At the time the studies were begun and at both places, average height of the site index trees was shorter at the widest spacing than at closer spacings. The difference was statistically significant only on the Cascade Head plots and amounted to 1.5 feet in 1963 between the widest spacing and the 8-foot spacing. We suspect that in the absence of a measured tree height criteria to avoid just such a situation, there was a tendency to accept shorter than ideal trees to accomplish the widest spacing requirements. There was no way to verify this at Cascade Head. We examined the diameter distribution of the site index trees at Clallam Bay immediately after thinning in 1971, but found no conclusive evidence to support our suspicions. Bigger trees have a growth advantage over their less favored associates. Trees with a slight height advantage early in life thus tend to increase their height advantage with time. This happened in both studies. The shorter trees in the widest spaced plots grew to statistically significant shorter heights later on, as compared with the trees growing at closer spacings. This is not a vital issue as we do not expect to grow trees at such extreme spacings at these young ages, but it is worth noting.

Height of 40 Largest Trees, Both Studies

Our attempt to assign height to the 40 largest trees per acre gave unacceptable results. Estimated height of the 40 largest trees at wide spacings were nearly the same as estimated height of site trees, HT 1. At closer spacing HT 40L consistently increased and exceeded the site heights, frequently by 5 to 10 feet. This was an artifact of the estimating procedure. Two factors were involved: (1) the diameter range of selected trees varied with spacing and (2) a volume equation was used to estimate tree heights.

There were 25 trees on most of the plots, and acreage varied with spacing. One tree on a closely spaced plot, when expanded to a per acre basis, represented more trees than one tree on the larger acreage of a wider spaced plot. Therefore, on close spacings, as we selected the 40 largest trees per acre from our plot data, one diameter class (the largest) often represented 40 trees per acre. By contrast, on wide spacings several diameter classes were required to accumulate the necessary 40 trees. As a consequence, average tree height was less on wider spacings because we included smaller trees in the sample in the first years (when total width of the diameter distributions among spacings was nearly the same within a study).

As the trees at the wider spacings grew, they developed larger diameters than did trees in the closer spacings and developed different volume-to-diameter relationships; that is, different mean tarif numbers. If the increasing size of diameters was accompanied by increasing height, wider spacings would have taller trees to match the larger diameters found in later years of the study. We would not expect this to happen, nor did our estimates of HT 1 or HT 30P suggest that it occurred. Why then would our estimates of HT 40L suggest that it did? By solving the standard volume equation for tree height, with diameter and volume given, we oversimplified the relationships. The known difference

in tarif numbers among treatments implied that the standard volume equation must be adjusted to a "local volume" relationship before it is applied to a given stand. Our failure to do that ignored different volume-to-diameter relationships caused by the early spacing differences. The treatments with the highest volume-to-diameter ratios (that is, largest tarif numbers) have the tallest HT 40L per acre.

For these reasons, we did not accept HT 40L, as defined here, as a valid estimate of plot height. If a field sample of heights of the 40 largest diameter trees per acre had been drawn, their average would have been free of the artificial procedural influence. Such a sample would not be free of the diameter distribution effect brought about in these studies by our expansion of different plot areas to a per acre basis.

HT 30P

HT 30P of the trees in the top 30 percent of the diameter distribution on each plot was nearly the same as the height of the site index trees. We accepted this height estimate as a valid average plot height indicator and used it to assign plot height in years when no height measurements were made. We plan to use this statistic as a plot variable in subsequent analyses.

A logical alternative source of a plot height estimate, projected site index heights, proved less useful in a preliminary test of proposed methods. Age variance was large on the Cascade Head study and led to erratic height estimates.

Site Index

Average site index of the two studies differed—109 feet at 50 years for the treated plots at Cascade Head and 124 feet at 50 years for the Clallam Bay study area. From this we expected the yield difference visible in the growth and yield data.

The variation of site index on these relatively small plots is high. The control plot at Cascade Head—located between the two blocks of plots—exceeded, for no apparent reason, the average site index of the other plots by 13 feet. The extreme spread of site index from lowest to highest was 19 and 15 feet for Cascade Head and Clallam Bay, respectively. (With this kind of variation on study areas selected with the hope, if not the knowledge, of site uniformity, one wonders at the level of practical usefulness of site index precision much finer than 15 site index points.)

The Clallam Bay site index estimate was unstable. The 1971 estimate of 129, reduced to 124 ten years later, could be an indicator that the regional site curves do not fit the stand. We believe, however, that this is a minor aberration that may have already stabilized. Planned remeasurements will verify the correct trend.

Yields

Yields in volume and basal area were greater on early thinning treatments at close spacings than on wide ones (see appendix tables). Yield in terms of Scribner board feet for trees 6 inches in diameter and larger—a popular unit of measure that defines the most marketable component of total volume—differed by spacings. At Clallam Bay, the 7.4- through 12.3-foot early thinning spacings produced more board-foot volume by the later years than did either of the wider spacings or the 4.0-foot close spacing. In the last 10 years the early thinnings to 8- and 12-foot spacings at Cascade Head produced more board-foot volume than did the wider spacings.

In general, the early thinning to 7- through 12-foot spacings have produced, so far, the most Scribner board-foot volume. At Clallam Bay, late thinning with about 500 trees per acre produced higher Scribner board-foot volume than did early thinning with fewer trees per acre.

Basal Area Increment

Gross basal area increment appears as a time trend for each of the thinning treatment spacings plotted by levels of basal area (figs. 5 and 6). The trends are different for the two studies. At the Clallam study all but the 17.6- and 21.8-foot early thinning spacings passed the culmination of annual basal area increment. This was true for the Cascade Head study only on the 8-foot spacing and the control. The 12-, 16- and 20-foot early thinning spacings either had a flattened increment trend as basal area increased or the trend continued to rise.

Another characteristic of basal area increment is shown in figures 7 and 8 where gross basal area increment is plotted by age for levels of basal area density. Figures 7 and 8 use the same data as are used in figures 5 and 6 but the data are viewed in a different way. The level of increment for a given age at Clallam Bay was slightly higher than at Cascade Head at 60 square feet of basal area and lower.

For high levels of basal area at age 21, the stands at Cascade Head grew faster than those at Clallam Bay. The sustaining or rising growth at high levels of basal area promises higher future increment for Cascade Head than for Clallam Bay if present trends continue. We think that the most recent levels of basal area increment at the Clallam Bay study are temporarily lower than average, and we expect an increase in the future. If this is true, then projected future trends of Clallam Bay will be at higher levels than those for Cascade Head at equivalent ages. Such would be the logical results of the two studies given their relative site indices.

Volume Increment

Gross volume increment trends appear in figures 9 and 10 by levels of basal area for each early thinning treatment through time. The control plot at Cascade Head appeared to reach a maximum current annual increment at 600 cubic feet per acre per year at 26 years and at 300 square feet of basal area. This exceeded the approximate maximum of 420 cubic feet per acre current annual increment estimated for the equivalent site index (Barnes 1962). This apparent maximum may be only a temporary level in a continuing upward trend.

The 4-foot control at Clallam Bay did not reach a maximum volume increment. The increments of the 7.4-, 9.2-, and 12.3-foot early thinning spacings did appear, however, to reach increment maxima. This occurred from ages 20 to 22 and was an unexpected result at such low ages. We assume these apparent increment maxima are temporary downturns of an otherwise steadily increasing increment trend.

Trends of volume increment by levels of basal area for selected ages appear in figures 11 and 12. Increment for the same ages was slightly although not consistently higher on the Clallam Bay study than on the (lower site index) Cascade Head study.

Diameter Increment

As expected, trees grown at wider spacings produced larger average diameters than did trees grown at closer spacings. At Cascade Head mean diameter of stands at the 20-foot spacing treatment exceeded the diameter of the 3.0-foot (control) treatment by 5.3 inches at age 29, 17 years after initial thinning. At Clallam Bay, mean diameter of thinnings to 21.8-foot spacing exceeded mean diameter of the 4.0-foot (control) spacing by 5.5 inches at age 22, 11 years after early thinning treatment.

Figures 13 and 14 show the trends of average diameter increment by early thinning treatment and by year for the two studies. In each study the two widest spacings had similar overlapping trends, indicating the increment was that of free-growing trees. By age 24 on the Cascade Head study, the trend of the 16-foot spacing reached a level between that of the 12- and 20-foot spacings; this trend indicated that the 16-foot spacing diameter increment was influenced by competition. A similar sorting of trends may be beginning in the last 3 years of the Clallam Bay study.

Ingrowth

Ingrowth, especially on the widely spaced treatments, increased the total cubic-foot volume, at least temporarily. Tree sizes were small, averaging 3 inches in diameter or less, and most are unlikely to become important to stands in the near future. We expect most ingrowth trees will eventually die as the main crown canopy closes. Presence of ingrowth trees confounds plot statistics, especially averages based on number of trees per unit area. This fact was sufficient justification in this study to exclude ingrowth trees from major consideration.

Mortality

The annual mortality loss to armillaria root rot was disturbing when well-spaced trees died on the thinned stands. Loss was high enough on two individual plots that, if it continues, future usefulness of the plots is questionable. The average of 5.3 percent of trees dying in 11 years (treatment 9.2, table 8), if projected to a 60-year rotation, would be 20 percent of the stand—an excessive amount. The present high number of diseased trees suggests that high mortality may continue. On the other hand, 2.1 percent of control plot trees dying in 11 years does not seem excessive. We believe that there is more armillaria root rot than normal on the thinned treatments, not necessarily because of thinning, but because of the unusual high basal damage to trees by mountain beaver.

Late Thinning at Clallam Bay

The pattern of increased increment following late thinning seems consistent in spite of the small size of the single plot thinned in the absolute control. All three late thinnings grew more cubic-foot volume increment than the early thinnings to which they were matched by level of basal area. The hypothesis that volume increment of late thinnings can be estimated by increment from stands thinned early that have reached the same level of basal area does not hold for hemlock for the 6 years examined. Nor does it hold consistently for basal area increment as examination of figure 6 verifies. This suggests that past modeling efforts to estimate thinned stand response, as equivalent to the response from stands of the same basal area that were thinned early, have underestimated hemlock growth.

There were no apparent differences in tree height growth that would help explain the volume increment differences between the early and late thinnings. Difference in form was not examined as a possible influence.

Basal area is not a sufficiently sensitive index of growing stock to distinguish increment of thinned from nonthinned stands. As shown in table 9, relative density failed to help explain the differences in volume increment. We examined the number of stems per acre, mean diameter, and the expression, "D times height-to-base-of-live-crown," as an estimator of cambium surface area. None were any better than relative density for explaining the volume increment behavior.

We do not know if the increased increment is a permanent shift of the increment trend or only a temporary change. It is important to find out.

The pattern of relatively low volume increment response for 3 years followed by relatively higher increment the next 3 years on all three late thinnings conforms to short-term reactions to thinning as described by Bradley (1963). The generally higher increment rate on the absolute control over the other two late thinnings may relate to the difference in diameter classes left after the late thinning. Note in table 31 that in the absolute control plot, half of the trees left were in the largest single diameter class that existed before thinning. By contrast, for the other two thinnings where the average diameter of trees cut equaled that of trees prior to cutting, the largest of the hemlock trees came from a wider portion of the diameter distribution. The same basal area could have been left on few trees of larger diameter with greater vigor and ability to respond. Had that been the method of tree selection at thinning, the volume response from the more vigorous trees might have been greater.

Effect of Form Difference on Volume Increment

Tree form was significantly influenced by early thinning treatments. A measured form quotient was required to discern differences in volume that remained hidden if tree diameter and height alone were the basis for volume estimation. The amount of volume error seemed to increase as stands aged, an important point to verify in future remeasurements. So far, failure to include a form quotient when estimating volume has not materially influenced interpretation of volume increment results.

Wood Quality, Both Studies

After a stand reaches 6 inches average diameter, the trees begin to grow into sizes valuable for sawn wood production. The time required to reach 6 inches is an indicator of useful wood production.

By age 20, the average diameter of most of the early thinning treatments in both studies reached 6 inches. In the two widest spacings on the higher site at Clallam Bay, the 6-inch average diameter was reached by age 17.

The rate at which wood grows, expressed as the number of rings per inch of wood, is an indicator of wood quality.

At age 20 there were less than four rings per inch in the 12-foot and wider spacings. By age 27 at the Cascade Head study, all early thinning treatments except the 20-foot spacing were growing at more than four rings per inch. It appears that few of the treatments will be growing trees with excessive rings per inch. This is important now because the stands have crossed the 6-inch diameter threshold into a period of wood value growth. The wider ringed central core of wood already established is the base on which better quality is being added.

There is doubt about the sensitivity of rings per inch of the average tree as an index to stand wood quality. Trees larger than stand average are the most dynamic part of the stand and grow faster than average. For this reason, the subject warrants further examination.

Acknowledgments

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We acknowledge the contribution to this study by Francis Herman (USDA Forest Service, retired) who had the foresight to design and install the Cascade Head early thinning study plots and by Jack Booth (USDA Forest Service) who remeasured and tended the plots for so many years. Norman A. Andersen (Washington State Department of Natural Resources) supervised all the remeasurements of the Clallam Bay study plots and was responsible for the flow of all data from field remeasurements into computer form, through editing, and to initial plot summarization.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 acre = 0.404686 hectare
1 square foot = 0.092903 square meter
1 cubic foot = 0.028316 cubic meter
1 square foot per acre = 0.229568 square meter per hectare
1 cubic foot per acre = 0.69972 cubic meter per hectare
°F = (9/5 °C) + 32

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Appendix

Table 12—Plot number, spacing, acreage, and number of trees per acre, by plot, Cascade Head, Oregon, and Clallam Bay, Washington

Location and plot number	Spacing of trees	Size of plot		Number of trees per acre
	-- Feet	- - - -	Acre	
Cascade Head:				
923	3	29.5x29.5	0.01998	4,104
915	8	44x46	.04646	581
916	8	44x48	.04518	664
917	12	60x60	.08264	302
918	12	60x60	.08264	351
919	16	80x80	.14692	177
920	16	80x80	.14692	170
921	20	100x100	.22957	109
922	20	100x100	.22957	109
Clallam Bay:				
335	4	25x30	.01721	2,615
350	4	25x30	.01722	2,842
352	4		.070045	2,327
353	4		.0416529	2,881
331	7.4	60x60	.08264	787
332	7.4	48x72	.07934	781
342	7.4	85x66	.12879	815
343	7.4	--	.15538	753
344	7.4	86.8x86.8	.17296	815
345	7.4	--	.16262	898
333	9.2	40x48	.04077	567
334	9.2	39x68	.06088	460
336	12.3	75.6x61.5	.10673	309
337	12.3	72x48	.07934	277
346	12.3	91.7x71	.14947	308
347	12.3	69x86	.13623	279
348	12.3	--	.13652	271
349	12.3	--	.17716	280
338	17.6	69.6x121.8	.19461	144
339	17.6	52.2x121.8	.14596	137
340	21.8	88x154	3111	90
341	21.8		.29439	92

-- = irregularly shaped plots, see figure 4.

Table 13—Number of stems per acre, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year: 12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
Feet		Number per acre						
3	923	4,004	3,754	3,053	2,603	1,852	1,502	1,201
8	915	581	581	581	581	581	581	581
	916	664	664	664	664	664	620	575
Average		623	623	623	623	623	600	578
12	917	302	302	302	278	278	278	278
	918	351	339	339	339	339	327	327
Average		327	321	321	309	309	302	302
16	919	177	177	177	170	170	170	170
	920	170	150	150	150	150	150	150
Average		174	163	163	160	160	160	160
20	921	109	109	109	109	109	109	109
	922	109	104	100	100	100	100	100
Average		109	107	104	104	104	104	104

Table 14—Diameter at breast height, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year: 12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
Feet		Inches						
3	923	2.29	2.75	3.47	4.20	5.17	6.05	7.10
8	915	2.07	3.10	4.59	6.02	6.70	7.49	8.25
	916	2.10	3.28	4.95	6.41	7.22	8.37	9.71
Average		2.09	3.19	4.77	6.22	6.96	7.93	8.98
12	917	2.23	3.21	4.87	6.86	7.86	9.02	10.4
	918	2.22	3.35	5.66	7.58	8.66	10.15	11.53
Average		2.23	3.28	5.27	7.22	8.26	9.59	10.97
16	919	1.98	3.19	5.39	7.60	8.83	10.38	11.98
	920	2.46	3.67	5.65	7.92	9.27	11.02	12.92
Average		2.22	3.43	5.52	7.76	9.05	10.70	12.45
20	921	1.88	2.99	5.21	7.53	8.90	10.76	12.93
	922	1.84	3.08	5.04	6.94	8.17	9.72	11.89
Average		1.86	3.04	5.13	7.24	8.54	10.24	12.41

Table 15—Net basal area per acre, by spacing treatment, plot, and total age. Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year: 12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
Feet		Square feet						
3	923	115.0	155.2	200.2	210.2	270.2	300.3	330.3
8	915	13.6	30.5	66.8	115.0	142.3	178.0	215.7
	916	16.0	38.9	88.7	148.9	189.0	237.1	295.7
Average		14.8	34.7	77.8	132.0	165.7	207.6	255.7
12	917	8.2	17.0	39.2	71.5	93.7	123.5	164.3
	918	9.4	20.7	59.1	106.3	138.6	183.6	236.9
Average		8.8	18.9	49.2	88.9	116.2	153.6	200.6
16	919	3.8	9.8	28.0	53.6	72.4	100.1	133.2
	920	5.6	11.0	26.1	51.2	70.1	99.2	136.2
Average		4.7	10.4	27.1	52.4	71.3	99.7	134.7
20	921	2.1	5.3	16.1	33.7	47.0	68.8	99.3
	922	2.0	5.4	13.9	26.3	36.5	51.6	77.3
Average		2.1	5.4	15.0	30.0	41.8	60.2	88.3

Table 16—Total net yield in cubic-foot volume, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year: 12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
Feet		Cubic feet						
3	923	1,496	2,432	3,859	5,861	7,002	8,669	10,580
8	915	132	328	936	2,042	2,886	4,317	6,464
	916	157	439	1,297	2,713	3,932	5,901	9,124
Average		145	384	1,117	2,378	3,409	5,109	7,794
12	917	88	195	534	1,248	1,857	2,867	4,563
	918	88	230	837	1,901	2,803	4,343	6,668
Average		88	213	686	1,575	2,330	3,288	5,616
16	919	33	100	370	890	1,383	2,256	3,654
	920	53	121	354	863	1,356	2,266	3,801
Average		43	111	362	877	1,370	2,261	3,728
20	921	17	50	200	526	852	1,492	2,580
	922	16	52	171	403	651	1,097	1,983
Average		17	51	186	465	752	1,295	2,281

Table 17—Net Scribner board-foot volume per acre, trees 6 inches and larger, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year						
		12 1963	14 1965	17 1968	20 1971	22 1973	25 1976	29 1980
Feet		Board feet						
3	923	0	160	1,451	4,324	7,497	13,564	23,784
8	915	0	0	214	2,154	4,567	9,862	18,885
	916	0	0	559	3,794	7,938	15,900	31,072
Average		0	0	387	2,974	6,253	12,881	24,979
12	917	0	0	263	1,873	3,974	8,095	16,245
	918	0	0	424	3,339	6,748	13,540	25,079
Average		0	0	344	2,606	5,361	10,818	20,662
16	919	0	0	174	1,445	3,243	7,112	14,063
	920	0	0	236	1,750	3,705	7,822	15,604
Average		0	0	205	1,598	3,474	7,467	14,834
20	921	0	0	60	818	2,041	4,857	10,304
	922	0	0	67	528	1,335	3,161	7,449
Average		0	0	64	673	1,688	4,009	8,876

Table 18—Number of stems per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year					
		11	12	14	17	20	22
		[illegible]	[illegible]	1974	[illegible]	1980	1982
Feet		Number per acre					
4.0	335	2,615	2,615	2,615	2,499	2,208	1,453
	350	2,847	2,847	2,847	2,847	2,557	1,685
Average		2,731	2,731	2,731	2,673	2,383	1,569
4.0, T	352	2,342	2,342	2,384	691	671	657
	353	2,881	2,881	3,025	672	672	[illegible]
Average		2,612	2,612	2,705	2,724/682*	672	662
7.4	331	787	787	762	750	[illegible]	714
	332	781	769	[illegible]	769	[illegible]	718
	342	815	815	784	777	753	652
	343	753	734	708	708	695	663
Average		784	776	756	751	730	687
7.4, T	344	815	799	769	451	[illegible]	[illegible]
	345	898	889	843	492	467	467
Average		857	824	806	790/472*	451	448
9.2	333	567	545	545	545	522	476
	334	461	460	394	394	378	312
Average		514	503	470	470	462	394
12.3	336	309	309	309	300	300	281
	337	277	277	265	265	265	252
	346	308	301	288	281	261	228
	347	279	272	272	272	272	257
	348	271	264	256	249	227	205
	349	280	280	280	280	280	268
Average		287	284	278	276	268	249
17.6	338	144	144	144	139	139	131
	339	137	137	137	137	123	123
Average		141	141	141	138	131	127
21.8	340	90	90	84	84	84	84
	341	92	88	85	82	82	82
Average		91	89	85	83	83	83

* = before/after thinning; T = thinned.

Table 19—Diameter at breast height, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year					
		11 1971	12 1972	14 1974	17 1977	20 1980	22 1982
Feet		Inches					
4.0	335	1.74	2.12	2.74	3.50	4.16	4.52
	350	1.47	1.81	2.48	3.29	3.88	4.32
Average		1.61	1.97	2.61	3.40	4.02	4.42
4.0, T	352	1.72	2.04	2.66	4.44	5.63	6.40
	353	1.79	2.06	2.55	4.43	5.69	6.55
Average		1.75	2.05	2.61	4.44*	5.66	6.48
7.4	331	1.92	2.36	3.52	5.17	6.40	7.01
	332	1.86	2.37	3.46	4.99	6.05	6.67
	342	1.87	2.29	3.44	5.09	6.21	6.87
	343	1.89	2.34	3.50	5.18	6.46	7.07
Average		1.89	2.34	3.48	5.11	6.28	6.91
7.4, T	344	1.84	2.30	3.49	5.25	7.13	8.00
	345	1.82	2.25	3.34	4.89	6.94	7.83
Average		1.83	2.28	3.42	5.07*	7.04	7.92
9.2	333	1.71	2.12	3.37	5.20	6.68	7.52
	334	1.85	2.29	3.47	5.50	7.03	7.97
Average		1.78	2.21	3.42	5.35	6.86	7.75
12.3	336	1.74	2.25	3.71	6.17	8.22	9.38
	337	1.84	2.32	3.66	5.93	7.97	9.23
	346	1.78	2.24	3.59	6.00	7.97	8.94
	347	1.83	2.29	3.56	5.69	7.41	8.39
	348	1.84	2.37	3.76	6.08	8.05	9.13
	349	1.83	2.26	3.52	5.62	7.42	8.44
Average		1.81	2.29	3.63	5.92	7.84	8.92
17.6	338	1.82	2.28	3.64	6.14	8.48	9.77
	339	1.87	2.34	3.68	6.10	8.47	9.84
Average		1.85	2.31	3.66	6.12	8.48	9.81
21.8	340	1.81	2.26	3.70	6.25	8.72	10.25
	341	1.84	2.28	3.51	5.98	8.34	9.60
Average		1.83	2.27	3.61	6.12	8.53	9.93

* = after thinning; T = thinned.

Table 20—Net basal area per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year					
		11 1971	12 1972	14 1974	17 1977	20 1980	22 1982
Feet		Square feet					
4.0	335	43.3	63.9	106.7	167.3	208.2	202.9
	350	33.7	51.0	95.3	168.2	218.8	224.6
Average		38.5	57.5	101.0	167.8	213.5	213.8
4.0, T	352	37.7	53.4	91.7	72.3	116.2	146.9
	353	49.3	66.9	107.5	71.9	118.6	157.1
Average		43.5	60.2	99.6	162/72.1*	117.4	152.0
7.4	331	15.9	24.0	52.7	109.3	162.0	191.6
	332	14.8	23.9	50.3	104.4	149.3	174.0
	342	15.5	23.4	51.2	109.6	158.5	175.8
	343	14.7	22.4	47.8	103.8	158.0	182.5
Average		15.2	23.4	50.5	106.8	157.0	181.0
7.4, T	344	15.1	23.2	51.5	76.1	120.2	151.6
	345	16.3	24.3	51.4	75.5	122.8	156.2
Average		15.7	23.8	51.5	110/75.8*	121.5	153.9
9.2	333	9.0	13.4	33.8	80.4	127.0	146.8
	334	8.6	13.2	27.6	65.1	102.0	113.2
Average		8.8	13.3	30.7	72.8	114.5	130.0
12.3	336	5.1	8.5	23.2	62.3	110.5	134.9
	337	5.1	8.1	20.1	50.9	91.8	117.0
	346	5.3	8.4	20.8	55.1	91.4	102.8
	347	5.1	7.9	18.8	48.0	81.4	98.7
	348	5.0	8.2	20.1	50.2	80.3	94.4
	349	5.1	7.8	18.9	48.3	84.0	105.5
Average		5.1	8.2	20.3	52.5	89.9	108.9
17.6	338	2.6	4.1	10.4	28.6	54.5	71.9
	339	2.6	4.1	10.1	27.8	48.1	64.9
Average		2.6	4.1	10.2	28.2	51.3	68.4
21.8	340	1.6	2.5	6.4	17.8	34.7	48.1
	341	1.7	2.6	5.9	16.3	31.1	41.2
Average		1.7	2.6	6.2	17.1	32.9	44.7

* = before/after thinning; T = thinned.

Table 21—Total net cubic-foot volume per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year: 11 1971	12 1972	14 1974	17 1977	20 1980	22 1982
Feet		Cubic feet					
4.0	335	384	643	1,319	2,719	4,232	4,913
	350	265	464	1,092	2,629	4,367	5,405
Average		325	554	1,206	2,674	4,300	5,159
4.0, T	352	310	497	1,086	1,227	2,438	3,450
	353	419	638	1,249	1,213	2,490	3,708
Average		365	568	1,168	2,496/1,220*	2,464	3,579
7.4	331	140	242	665	1,799	3,346	4,451
	332	123	235	619	1,695	3,043	3,986
	342	133	230	640	1,806	3,275	4,100
	343	130	223	591	1,701	3,263	4,241
Average		132	233	629	1,750	3,232	4,195
7.4, T	344	123	218	632	1,284	2,558	3,641
	345	142	241	623	1,253	2,595	3,727
Average		133	230	628	1,803/1,269*	2,577	3,684
9.2	333	69	118	390	1,238	2,471	3,221
	334	77	132	335	1,025	2,019	2,533
Average		73	125	362	1,132	2,245	2,877
12.3	336	39	73	263	969	2,203	2,975
	337	40	72	231	785	1,829	2,585
	346	41	73	234	849	1,816	2,260
	347	40	71	210	727	1,585	2,133
	348	40	74	232	778	1,596	2,076
	349	41	73	213	733	1,641	2,288
Average		40	73	231	807	1,778	2,386
17.6	338	20	37	118	447	1,046	1,543
	339	21	39	117	434	922	1,388
Average		20	38	118	440	984	1,466
21.8	340	12	22	70	269	648	1,002
	341	13	22	62	244	574	850
Average		12	22	66	256	611	926

* = before/after thinning; T = thinned.

Table 22—Net Scribner board-foot volume per acre, trees 6 inches and larger, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year of measurement: 11 1971	12 19[illegible]	14 1974	17 1977	20 1980	22 1982
Feet							
4.0	335	[illegible]	0	[illegible]	[illegible]	2,352	4,564
	350	0	0	[illegible]	[illegible]	2,180	4,529
Average		0	0	0	[illegible]	2,266	[illegible]
4.0, T	352	0	[illegible]	0	[illegible]	1,242	3,646
	353	0	[illegible]	[illegible]	0	902	3,726
Average		0	[illegible]	[illegible]	30*	[illegible]	3,686
7.4	[illegible]	0	[illegible]	0	[illegible]	4,300	7,692
	332	0	0	[illegible]	539	3,203	5,935
	342	0	0	[illegible]	978	4,511	7,572
	343	0	[illegible]	43	539	3,571	6,710
Average		0	[illegible]	20	701	3,829	6,977
7.4, T	[illegible]	0	[illegible]	0	498	3,687	7,823
	345	0	[illegible]	0	[illegible]	3,666	7,596
Average		[illegible]	[illegible]	[illegible]	680/517*	3,677	7,710
[illegible]	333	0	[illegible]	0	[illegible]	2,972	5,844
	334	[illegible]	[illegible]	0	360	2,852	5,401
Average		0	0	0	[illegible]	2,912	5,623
12.3	[illegible]	0	0	0	[illegible]	4,435	8,064
	337	0	0	0	[illegible]	3,950	7,379
	346	0	0	0	409	3,650	6,065
	347	0	0	0	[illegible]	2,674	5,077
	348	0	0	0	364	3,140	5,552
	349	[illegible]	0	0	[illegible]	2,918	5,648
Average		0	0	0	[illegible]	3,461	6,298
17.6	338	0	0	[illegible]	290	2,342	4,585
	339	0	0	0	329	1,993	4,041
Average		0	0	[illegible]	310	2,168	4,313
21.8	340	0	0	0	165	1,447	3,021
	341	0	0	0	108	1,190	[illegible]
Average		0	0	0	137	1,319	[illegible]

* = before/after thinning; T = thinned.

Table 23—Average annual tree diameter increment, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year of increment: 12 1964	14 1966	17 1969	20 1972	22 1974	27 1978
Feet		- - -

Table 24—Gross annual increment in basal area per acre, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year of increment					
		12 1964	14 1966	17 1969	20 1972	22 1974	27 1978
Feet		Square feet					
3	923	16.0	10.4	23.5	12.5	15.2	13.2
8	915	5.3	10.1	16.8	14.1	12.0	9.4
	916	7.4	14.3	21.0	20.8	16.5	15.8
Average		6.4	12.2	18.9	17.5	14.3	12.6
12	917	2.5	6.1	11.1	11.1	10.4	10.2
	918	3.4	9.9	16.6	17.4	12.9	13.3
Average		3.0	8.0	13.9	14.3	11.7	11.8
16	919	1.9	4.3	8.6	9.3	8.1	8.3
	920	2.2	3.7	8.9	9.6	10.2	9.4
Average		2.1	4.0	8.8	9.5	9.2	8.9
20	921	1.0	2.6	6.3	6.5	6.6	7.6
	922	1.1	2.4	3.9	4.8	4.3	6.5
Average		1.1	2.5	5.1	5.7	5.5	7.1

Table 25—Gross annual increment in cubic-foot volume per acre, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year of increment					
		12 1964	14 1966	17 1969	20 1972	22 1974	27 1978
Feet		Cubic feet					
3	923	362	333	762	550	675	606
8	915	59	152	345	408	440	537
	916	88	223	442	592	608	835
Average		74	188	394	500	524	686
12	917	29	82	212	290	322	424
	918	39	137	328	454	426	581
Average		34	91	270	372	374	503
16	919	21	55	154	232	243	349
	920	26	51	159	240	290	384
Average		24	53	157	236	267	367
20	921	10	30	103	151	184	272
	922	12	29	65	111	124	222
Average		11	30	84	131	154	247

Table 26—Gross annual increment in Scribner board-foot volume per acre, by spacing treatment, plot, and total age, Cascade Head, Oregon

Spacing treatment	Plot number	Total age and year of increment: 12 1964	14 1966	17 1969	20 1972	22 1974	27 1978
Feet		Board feet					
3	923	0	227	982	1,224	1,812	2,555
8	915	0	0	452	1,079	1,497	2,256
	916	0	31	732	1,921	2,316	3,793
Average		0	16	592	1,500	1,907	3,025
12	917	0	25	333	969	1,238	2,037
	918	0	0	727	1,652	1,761	2,885
Average		0	13	530	1,311	1,500	2,461
16	919	0	0	261	776	1,010	1,738
	920	0	0	349	939	1,255	1,945
Average		0	0	305	858	1,133	1,842
20	921	0	0	153	534	771	1,362
	922	0	4	89	331	465	1,070
Average		0	2	121	433	618	1,216

Table 27—Average annual tree diameter increment, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year of increment: 11 1972	14 1975	17 1978	20 1981
Feet		Inches			
4	335	0.38	0.25	0.18	0.11
	350	.34	.30	.23	.25
Average		.36	.28	.20	.18
4, T	352	.32	.29	.43	.40
	353	.29	.24	.41	.46
Average		.31	.26	.42*	.43
7.4	331	.44	.60	.41	.30
	332	.51	.54	.38	.27
	342	.42	.61	.40	.25
	343	.45	.60	.46	.31
Average		.45	.59	.41	.28
7.4, T	344	.46	.62	.77	.46
	345	.43	.54	.96	.51
Average		.45	.58	.87*	.48
9.2	333	.41	.63	.46	.50
	334	.44	.77	.56	.38
Average		.43	.70	.51	.44
12.3	336	.51	.85	.76	.57
	337	.48	.79	.69	.57
	346	.46	.79	.70	.53
	347	.46	.75	.60	.45
	348	.53	.77	.66	.49
	349	.43	.70	.65	.51
Average		.48	.78	.67	.52
17.6	338	.46	.73	.82	.67
	339	.47	.73	.70	.77
Average		.46	.73	.76	.72
21.8	340	.45	.83	.81	.80
	341	.44	.85	.86	.66
Average		.44	.84	.83	.73

* = excluding the effect of altering mean stand diameter by thinning;
T = thinned.

Table 28—Gross annual increment, by spacing treatment, plot, and total age in basal area per acre, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year of increment: 11 1972	14 1975	17 1978	20 1981
Feet		Square feet			
4	335	20.6	20.4	16.9	11.5
	350	17.3	24.6	20.5	13.9
Average		19.0	22.5	18.7	12.7
4, T	352	15.7	20.5	14.4	16.7
	353	17.6	21.3	14.1	20.1
Average		16.7	20.9	14.3*	18.4
7.4	331	8.1	17.9	18.1	15.7
	332	9.3	16.8	16.4	12.6
	342	7.9	18.9	18.1	12.9
	343	7.7	17.0	18.9	15.9
Average		8.3	17.7	17.9	14.3
7.4, T	344	8.4	19.5	15.5	16.3
	345	8.4	17.9	16.2	18.5
Average		8.4	18.7	15.9*	17.4
9.2	333	5.3	13.8	14.9	15.1
	334	4.6	11.1	13.9	11.3
Average		5.0	12.5	14.4	13.2
12.3	336	3.4	11.2	16.2	15.1
	337	3.0	8.5	12.4	13.5
	346	3.1	9.5	13.9	11.0
	347	2.9	8.7	10.7	10.1
	348	3.2	8.5	11.4	9.7
	349	2.7	8.3	11.6	12.1
Average		3.1	9.1	12.7	11.9
17.6	338	1.5	4.6	8.1	9.0
	339	1.5	4.4	6.8	9.2
Average		1.5	4.5	7.5	9.1
21.8	340	1.0	3.0	4.9	6.8
	341	.9	2.9	4.6	5.1
Average		1.0	3.0	4.8	6.0

* = after thinning; T = thinned.

Table 29—Gross annual increment in cubic-foot volume per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year of increment			
		11 1972	14 1975	17 1978	20 1981
Feet		Cubic feet			
4.0	335	259	408	524	562
	350	199	440	590	639
Average		229	424	557	601
4.0, T	352	187	399	362	527
	353	219	403	354	619
Average		203	401	358*	573
7.4	331	103	311	486	549
	332	112	291	444	453
	342	97	328	489	479
	343	93	294	498	548
Average		101	306	479	507
7.4, T	344	98	339	404	531
	345	102	305	418	588
Average		100	322	411*	560
9.2	333	56	222	359	466
	334	55	181	333	359
Average		56	202	346	413
12.3	336	34	175	353	443
	337	32	132	272	390
	346	33	148	304	330
	347	32	134	235	300
	348	36	134	253	290
	349	31	127	253	347
Average		33	142	272	350
17.6	338	17	72	175	249
	339	18	69	150	248
Average		18	70	162	249
21.8	340	10	47	100	172
	341	10	45	93	132
Average		10	46	97	152

* = after thinning; T = thinned.

Table 30—Gross annual increment in Scribner board-foot volume per acre, by spacing treatment, plot, and total age, Clallam Bay, Washington

Spacing treatment	Plot number	Total age and year of increment: 11 1972	14 1975	17 1978	20 1981
Feet		Board feet			
4.0	335	0	59	405	1,025
	350	0	0	440	1,058
Average		0	30	423	1,042
4.0, T	352	0	0	161	1,073
	353	0	0	50	1,238
Average		0	0	106*	1,156
7.4	331	0	35	744	1,679
	332	0	39	648	1,208
	342	0	74	888	1,550
	343	0	52	727	1,578
Average		0	50	752	1,522
7.4, T	344	0	7	725	1,869
	345	0	76	701	1,969
Average		0	42	713*	1,919
9.2	333	0	0	426	1,498
	334	0	4	531	1,282
Average		0	2	479	1,390
12.3	336	0	0	914	1,864
	337	0	0	723	1,696
	346	0	0	741	1,354
	347	0	6	487	1,215
	348	0	0	627	1,177
	349	0	3	530	1,352
Average		0	2	670	1,443
17.6	338	0	0	481	1,076
	339	0	12	376	1,058
Average		0	6	429	1,067
21.8	340	0	0	253	746
	341	0	0	222	557
Average		0	0	238	652

* = after thinning; T = thinned.

Table 31—Average number of trees per acre, by diameter class, for spacing treatments and selected years, Cascade Head, Oregon

Diameter class	Treatment														
	3-foot control, plot 923 (0.01998 acre)			8-foot spacing, plots 915-916 (0.09164 acre)			12-foot spacing, plots 917-918 (0.16528 acre)			16-foot spacing, plots 919-920 (0.29384 acre)			20-foot spacing, plots 921-922 (0.45914 acre)		
	1963	1971	1980	1963	1971	1980	1963	1971	1980	1963	1971	1980	1963	1971	1980
Inches	Number of trees														
1	1,952	551	--	196	--	--	60	--		34	-		44		
2	851	551	50	295	11	11	175	6		82	3		44		
3	751	450	300	98	66	22	67	12		48	--		22	2	
4	250	400	100	33	109	55	24	12		10	7			4	
5	150	250	300		66	44		30			14			11	
6	100	300	150		131	66		67	12		27			22	2
7		100	50		109	33		60	24		24	17		26	--
8		100	200		44	76		24	24		27	7		15	2
9		50	150		66	87		67	54		24	7		17	9
10			150		11	33		24	42		24	17		4	11
11			50		11	76		6	30		7	20		2	20
12						55			18			17			13
13						11			42			10			9
14						11			18			20			15
15						11			24			27			13
16						11			6			7			6
17									--			10			4
18									6						
Total trees	4,004	2,603	1,201	622	622	600	327	309	302	174	163	160	108	104	104
Total basal area	115	251	329	14.8	132	256	8.8	[illegible]	201	4.7	52	135	2.1	30	88

-- = no data.

Table 32—Average number of trees per acre, by diameter class, for spacing treatments and selected years, Clallam Bay, Washington

	Treatment																			
				4.0-foot control, plots 332 and 342 (0.01 acre)		4.0-foot control with late thinning, plots 332 and 342 (0.034 acre)			7.4-foot initial spacing; plots 331, 332, 341, and 343 (0.446 acre)		7.4-foot initial spacing, then thinned, plots 344-345 (0.336 acre)			9.2-foot initial spacing, plots 333-345 (0.105 acre)		12.3-foot initial spacing; plots 336, 337, 346, 347, 348, and 349 (0.784 acre)		17.6-foot initial spacing, plots 338-339 (0.340 acre)		21.8-foot initial spacing, plots 340-341 (0.606 acre)	
				1971	1983	1977		1983	1971	1983	1971	1977		1983	1971	1983	1971	1983	1971	1983	1971	1983
						Before thin	After thin					Before thin	After thin									
[illegible]	9,400			[illegible]		474			282		319				200		73		38		25	
[illegible]	5,600	100		1,162	145	[illegible]	18		[illegible]		417	24	6		228		196		88		59	
[illegible]	1,400	300	[illegible]	116	[illegible]	618	98	[illegible]	110	27	104	107	21	3	57	19	18	4	15		7	
4	600	400	[illegible]	58	436	[illegible]	251	63	[illegible]	47	15	191	92	9	10	[illegible]		4				
[illegible]					378	269	197	63	[illegible]	94		209	134	21		0		17		6		
6			100		174	152	98	161		121		152	110	68		48		17		3		3
[illegible]			[illegible]		[illegible]	36	9	134		[illegible]		68	60	77		38		14		0		2
[illegible]			[illegible]		58			[illegible]		90		36	24	68		133		23		18		5
[illegible]								19		81				77		57		50		20		15
[illegible]					[illegible]			9		52				60		38		45		12		12
11					29					29				36		19		45		29		16
[illegible]										4				18		19		28		26		18
[illegible]										[illegible]				3				4		9		10
[illegible]																				9		2
[illegible] [illegible]	17,000	800	800	2,731	1,598	2,641	672	662	782	677	885	787	447	441	495	382	287	249	141	132	91	83
Total basal area	271	52	172	38.3	230.5	159.1	72.2	168.5	15.2	192.6	15.6	110.3	72.6	167.2	8.7	140.1	5.2	117.9	2.6	79.7	1.6	50.4

[illegible] Because trees from plots were combined to get averages, the total number of trees may differ slightly from averages given in table 18

Hoyer, Gerald E.; Swanzy, Jon D. Growth and yield of western hemlock in the Pacific Northwest following thinning near the time of initial crown closure. Res. Pap. PNW-365. Portland, OR. U.S. Department of Agriculture; Forest Service, Pacific Northwest Research Station; **1986.** 52 p

Growth, stand development, and yield were studied for young, thinned western hemlock (*Tsuga heterophylla* Raf. [Sarg.]). Two similar studies were located at Cascade Head Experimental Forest in the Siuslaw National Forest, western Oregon, and near Clallam Bay on the Olympic Peninsula in Washington. At the latter, first thinnings were made at two ages; one at about the time of initial crown closure (early or crown-closure thinning) and the other after competition was well underway (late or competition thinning).

Stands, age 7 at breast height at time of crown closure thinning, were grown for 17 years at Cascade Head and for 11 years at Clallam Bay. In addition, 6 years after (early) crown-closure thinning the first (late) competition thinning was made at Clallam Bay on previously prepared, well-stocked stands. The tree spacing on the early thinnings ranged from 3 feet to 22 feet.

At ages 24 and 18 breast height on the two studies, stands with the most stocking produced the most cubic-foot volume and volume increment and the smallest average diameter. Early thinnings spaced between 7 and 12 feet produced the most usable wood in terms of Scribner board-foot volume of trees 6 inches in diameter and larger.

During the 6-year period following the late thinning, the treatments produced 55, 86, and 180 more cubic-foot volume increment per acre per year than did early thinnings that grew to the same basal area. The studies provide an approximation of the behavior of stands grown at given plantation spacings. The studies suggest that volume increment from stands thinned late differs from the volume increment of early thinning or planted stands that have attained basal area density similar to the late-thinned stands. Representative growth and yield data is provided for all treatments.

Keywords: Spacing thinnings, stand development, increment, yield (forest), western hemlock.

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Early Survival and Growth of Planted Douglas-Fir With Red Alder in Four Mixed Regimes

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Abstract

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To quantify between-species interactions, we measured and compared survival and growth of planted Douglas-fir and associated planted and volunteer red alder at a location on the west side of the Cascade Range in Washington. The planted alder were wildlings dug either from a nearby area or from a distant, coastal site and interplanted into a 3-year-old Douglas-fir plantation. The volunteer alder became established in year 1; these were cut at year 3 or 7 depending on the regime tested.

The data indicated no apparent advantage in using nonlocal red alder to reduce aboveground competition with Douglas-fir at this location. Survival of both sources of interplanted alder was high, and the average diameter and height were similar through plantation age 10. Retaining about 1 100 volunteer alder per hectare (445/acre) through plantation age 7 had no measurable positive or negative effect on the associated Douglas-fir.

When alder densities are less than about 1 250/ha (500/acre), silviculturists can safely delay alder control on most average or below-average site quality land until 6 to 8 years after planting Douglas-fir. This reduces alder sprouting and permits combining complete or partial control of alder with precommercial thinning of associated Douglas-fir. To ensure timely control, periodic observations of Douglas-fir red alder mixtures are necessary, however.

Keywords: Silvicultural systems, mixed stands, competition (plant), nitrogen fixation, Douglas-fir, *Pseudotsuga menziesii,* red alder, *Alnus rubra.*

Summary

At a Douglas-fir site III location on the west side of the Cascade Range in Washington, we compared 10-year survival and growth of planted Douglas-fir in four regimes with planted or volunteer red alder. The regimes were Douglas-fir with interplanted alder wildlings of either (1) a local source or (2) a distant, coastal source; and Douglas-fir with volunteer red alder present (3) through plantation age 3 or (4) through plantation age 7.

Our purpose was to quantify between-species interactions. The data indicated no apparent advantage in using nonlocal red alder to reduce aboveground competition with Douglas-fir at this location. Survival of both sources of interplanted alder was high; their average diameter and height were similar and exceeded that of associated Douglas-fir through plantation age 10. Average percentage of sprouting stumps and average height of the tallest sprout per stump did not differ for the two alder sources.

Delaying release of Douglas-fir from volunteer alder until age 7 instead of at age 3 did not reduce Douglas-fir density nor reduce average height and diameter at breast height through plantation age 10. Retaining a heavy component of volunteer (1 100/ha) or planted (2 100/ha) red alder through plantation age 7 had no measurable positive or negative effect on the associated Douglas-fir. When density of

volunteer alder is less than about 1 250/ha, silviculturists can delay alder control on most average or below-average site quality land until 6 to 8 years after planting Douglas-fir. This delayed cutting reduces alder sprouting and permits combining complete or partial control of alder with precommercial thinning of associated Douglas-fir. To balance the potential positive and negative effects of red alder in Douglas-fir plantations, control of alder density can be delayed until the upper crown of Douglas-fir crop trees is in contact with nearby alder. Periodic observations, especially during the first decade after planting, are necessary to ensure timely control.

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Introduction

Red alder (*Alnus rubra* Bong.) is a commercial tree species that can provide nitrogen to improve growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantations. For example, a 2:1 mixture of red alder:Douglas-fir at the Wind River Experimental Forest, Gifford Pinchot National Forest, in southwestern Washington provided at least 40 kg $N \cdot ha^{-1} \cdot yr^{-1}$ during a 30-year period (Tarrant and Miller 1963) and markedly increased growth of planted Douglas-fir at that N-deficient site (Miller and Murray 1978, Tarrant 1961). Red alder can be established in Douglas-fir plantations through natural seeding, by concurrent interplanting, or by delayed interplanting to offset the early competitive advantage of red alder over Douglas-fir. These mixed-species systems involve sharing site resources between an N-fixing species and a principal crop species.

Using red alder as an alternative to nitrogen fertilizer does have disadvantages (Miller and Murray 1979). One major disadvantage is that early height growth of red alder exceeds that of Douglas-fir. Consequently, faster growing red alder will overtop nearby, equal-aged Douglas-fir for at least 25 years (Fowells 1965, Newton and others 1968, Miller and Murray 1978), and a large proportion of Douglas-fir may be top-damaged or die unless spacing of the two species is controlled.

Before mixed Douglas-fir/red alder plantations can be recommended as a management option for mesic sites in western Washington and Oregon, some important questions need to be answered at a number of trial locations: (1) Will interplanted red alder of a nonlocal source be less competitive with Douglas-fir than interplanted red alder of a local source? (2) When should surplus alder be cut? (3) After surplus alder are cut, what are the occurrence rate and size of alder sprouts? (4) During the various stages of plantation development, how many red alder should be admixed with Douglas-fir to provide adequate N production with an acceptable level of competition? (5) What is the comparative growth of Douglas-fir plantations that have red alder as a source of N rather than urea fertilizer?

In spring 1974, a study began at a location on the west side of the Cascade Range in Washington to answer the first question; that is, a nonlocal vs. a local source of alder.[1/] To approximate the well-documented, mixed plantation in the Wind River Experimental Forest in southwestern Washington, a 2:1 red alder:Douglas-fir mixture was established by interplanting two red alder adjacent to each Douglas-fir in a 3-year-old Douglas-fir plantation. Local red alder were interplanted on three study plots and nonlocal alder were interplanted on three others. Immediately before this interplanting, volunteer red alder were felled on these six plots and on three adjacent control plots. When the plantation was 7 years old we anticipated, however, that the 2:1 ratio would eventually result in a large proportion of dead or damaged Douglas-fir. From our earlier observations at the Wind River mixed plantation, we estimated that 50 to 100 uniformly distributed, dominant red alder per hectare would improve N and organic matter status, but would not seriously reduce Douglas-fir growing stock (Miller and Murray 1978.) Consequently, we expanded the study at White River to provide answers to the four other questions.

[1/]This study was initiated by Weyerhaeuser Company on the White River Tree Farm. It is now a cooperative study between Weyerhaeuser and the Pacific Northwest Research Station, USDA Forest Service.

This report documents stand development through Douglas-fir plantation age 10 years, when alder and Douglas-fir densities were reduced to prescribed levels and urea fertilizer was applied in one regime. We compare early survival and growth of (1) Douglas-fir in competition with either interplanted or volunteer alder, and (2) interplanted alder from two sources. Included are the number and size of alder sprouts. Future reports will update the answers to the first three questions and provide initial information on the growth of Douglas-fir with varying densities of admixed alder and with N fertilizer (questions 4 and 5).

Materials and Methods

Study Area

The study is located in a Douglas-fir plantation about 6 km east of Enumclaw, Washington, at 540 m in elevation. The moderately deep, well-drained soil of the site is Pitcher sandy loam, which developed from a mixture of volcanic ash and basaltic rock (Duncan and others 1973). Douglas-fir site index on this soil averages 33.5 m (site III) at age 50 years at breast height (Duncan and others 1973). The area had been clearcut, then logged and scarified by tractor; logging slash was piled, but not burned. The plantation was established in spring 1971 when 2 + 1 Douglas-fir seedlings were hand planted at an average density of 1 480/ha.

Treatments

Treatments were applied to twelve 0.08-ha areas. A 0.04-ha tree measurement plot was centered in each treatment area; this left a 4.1-m-wide buffer. Treatments were applied 3, 7, and 10 years after planting (table 1). At age 3, the plantation contained volunteer trees of red alder, Douglas-fir, and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). On six plots, all volunteer alder were cut and two 2-year-old red alder wildlings were interplanted near each Douglas-fir; one at a distance of 45 cm from the Douglas-fir and the other at 90 cm. Alder from a local source (regime 1) were planted on three of the six plots, and alder from a nonlocal source near sea level (regime 2) at Aberdeen, Washington, were planted on three other plots.

Likewise on three additional plots, all volunteer alder were cut. Two years later, alder stump sprouts and new alder seedlings were cut and treated with TORDON[2/] herbicide to maintain these three plots in an alder-free condition (regime 3). The three plots of regime 4 were installed 4 years after those of the other regimes.

[2/]The use of trade, firm, or corporation names does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Table 1—Schedule of treatments by regime

Years after planting Douglas-fir	Regime (3 plots per regime)			
	1	2	3	4
3	All volunteer red alder cut; 2 local red alder wildlings planted adjacent to each Douglas-fir	As regime 1, but 2 nonlocal red alder wildlings planted adjacent to each Douglas-fir	All volunteer red alder cut	No treatment
5	No treatment	No treatment	Red alder sprouts and new seedlings cut; stumps treated with herbicide	No treatment
7	Most red alder cut except 50, 100, or 200/ha retained on one plot each	As regime 1	Red alder sprouts and new seedlings cut	All volunteer red alder cut
10	Douglas-fir reduced to 740/ha; new red alder sprouts and seedlings cut	As regime 1	As regimes 1 and 2	As other regimes; 224 kg N/ha as urea applied

At plantation age 7, red alder were cut from all plots. Some alder were retained on plots and buffers of regimes 1 and 2 at a density of 50, 100, or 200/ha following random assignment of these densities within each alder source. Although all alder in regimes 3 and 4 were scheduled for cutting, some were missed as determined at remeasurement 3 years later.

At plantation age 10 years, all western hemlock exceeding 1.3 m in height were cut as were surplus alder seedlings and stump sprouts (fig. 1). Douglas-fir was reduced to 740 trees/ha (300/acre) on all regimes. Average number of stems before and after cutting at ages 7 and 10 years is shown in table 2. Finally, plots of regime 4 were fertilized with 224 kg N/ha as urea.

Measurements

Tree diameters at breast height (d.b.h.) were measured at 1.3 m above ground. D.b.h. and height of Douglas-fir, hemlock, and alder were measured after the 1977 and 1980 growing seasons (plantation ages 7 and 10); height of planted Douglas-fir was also recorded after the 1973, 1974, 1975, and 1976 growing seasons.

Statistical Analyses

Analysis of variance and Tukey's Test were used to determine whether real differences existed among treatment means. These analyses were based on a completely random experiment, although the adjacent plots of regime 4 were installed 4 years after those of the other regimes. The 10-percent probability level was used to indicate statistical significance. The analysis for the 3- and 7-year data is of four treatments with three replicates of each treatment. The analysis of the 10-year data is less straightforward because the three plots in regimes 1 and 2 had differing alder densities (50, 100, and 200/ha). Although these densities were balanced within both regimes, they were not true replicates. Despite this, we treated them as replicates in our analyses.

Figure 1.—Interplanted red alder (local seed source) and associated Douglas-fir at plantation age 10 and before felling surplus conifers. A crop alder is behind the sign and 3-year-old alder sprouts are to the right; 50 alder per ha were retained at age 7 years.

Table 2—Average number of stems before removal and after removal (in parentheses) of surplus alder and conifer at plantation ages 7 and 10 years

Regime	Douglas-fir					Red alder	
	Planted		Volunteers	Hemlock, volunteers		Planted, age 7 yr	Volunteers, age 7 yr 1/
	Age 7 yr 2/	Age 10 yr	Age 7 yr	Age 7 yr	Age 10 yr		
	Number per hectare						
Douglas-fir/planted alder:							
1. Local alder	1 095	1 070 (740)	123 (0)	239 (99)	99 (0)	1 787 (50, 100, 200) 3/	198(0)
2. Nonlocal alder	1 177	1 169 (740)	74 (0)	33 (33)	33 (0)	2 207 (50, 100, 200) 3/	165(0)
Douglas-fir/volunteer alder:							
3. Alder cut at age 3	1 243	1 218 (740)	82 (0)	288 (91)	91 (0)		280(0)
4. Alder cut at age 7	1 276	1 251 (740)	189 (0)	107 (41)	41 (0)		1 120(0)

1/ The number of volunteer alder at age 10 are shown in table 5. These alder were either missed in the cutting at age 7 or were new volunteers. All were cut at age 10.

2/ No planted Douglas-fir were cut at age 7; difference between number of stems before cutting at 10 years and at 7 years is mortality.

3/ Alder were reduced to 50/ha on 1 plot and 100 or 200/ha on the remaining plots; these crop trees were retained at age 10.

Results

Planted Douglas-Fir

Survival.—We do not know how volunteer alder affected survival and growth of Douglas-fir before plantation age 3 (equal to seedling age 6). The number of planted Douglas-fir per hectare present at age 7 and estimated survival percentage between years 3 and 7 did not vary significantly among the four regimes (table 3). Survival of Douglas-fir released from competition with 1 120/ha volunteer red alder at age 7 (regime 4) was not significantly different from survival of Douglas-fir released at age 3 (regime 3). Thus, delaying release of Douglas-fir from 1 120 volunteer alder/ha until age 7 did not reduce survival. We suspect, however, that further delay would have eliminated or damaged potential crop trees.

Growth.—D.b.h. of mean basal area (Dg) of the Douglas-fir did not vary significantly among the four regimes (table 4); thus, neither planted nor volunteer alder reduced Dg of associated Douglas-fir through plantation age 7 when surplus alder were cut. Three years later, Dg remained not significantly different among the four regimes.

Average height of Douglas-fir did not differ significantly among the four regimes at plantation age 3 when volunteer alder were cut in three regimes (table 4). Four years later, unreleased Douglas-fir in regime 4 averaged about 10 percent shorter than released Douglas-fir on regime 3, but this difference was not statistically significant. Further alder influence in regimes 3 and 4 was limited to that of 91 or 272 sprouts/ha, respectively, and of a few new volunteers (table 5). At the same time, alder influence in regimes 1 and 2 was reduced to 50, 100, or 200/ha uniformly spaced, dominant or codominant trees, plus an average of 354 or 230 sprouts/ha, respectively, as disclosed in the next inventory (table 5). Average height of Douglas-fir in regime 4 was significantly less than in regimes 1 and 2 at plantation age 7 years; by plantation age 10 years, however, average height of Douglas-fir among the four regimes did not differ significantly (table 4).

Table 3—Average number of planted Douglas-fir and red alder before cutting (at plantation ages 3 and 7 years) and survival percentage during that period

	Douglas-fir			Red alder		
Regime	Age 3	Age 7	Survival	Age 3	Age 7	Survival
	no./ha		percent	no./ha		percent
Douglas-fir/planted alder:						
1. Local alder	1 144	1 095	95.7	2 288	1 787	78.1
2. Nonlocal alder	1 226	1 177	96.0	2 452	2 207	90.0
Douglas-fir/volunteer alder						
3. Alder cut at age 3	1 284	1 243	96.8			
4. Alder cut at age 7	1 293	1 276	98.7			
Differences among regime means	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

N.S. = not significant.

Table 4—Average size of planted Douglas-fir at designated plantation ages

Regime	Dg		Height		
	Age 7	Age 10	Age 3	Age 7	Age 10
	mm		m		
Douglas-fir/planted alder:					
1. Local alder	40	83	0.9	3.7b	6.4
2. Non-local alder	40	85	0.9	3.7b	6.5
Douglas-fir/volunteer alder:					
3. Alder cut at age 3	40	85	0.8	3.6ab	6.5
4. Alder cut at age 7	36	79	0.8	3.2a	5.8
Differences among regime means	N.S.	N.S.	N.S.	1/	N.S.

N.S. = not significant.

1/ Values in same vertical column with different letter are significantly different ($P < 0.10$).

Table 5—Average number of red alder stump sprouts and volunteers, and average height of tallest sprout per stump at plantation age 10 (3 years after cutting)

Regime	Stumps with sprouts		Tallest sprout	Volunteers
	no./ha	percent	m	no./ha
Douglas-fir/planted alder:				
1. Local alder	354	19	3.7b	41
2. Nonlocal alder	230	10	3.7b	74
Douglas-fir/no volunteer alder:				
3. Alder cut at age 3	91	32	4.9a	8
4. Alder cut at age 7	272	24	3.7b	16
Differences among regime means	--	N.S.	1/	--

-- = negligible; N.S. = not significant.

1/ Values in same vertical column with different letter are significantly different ($P < 0.10$).

Planted Red Alder

Survival.—Average 4-year survival percentage of interplanted alder did not vary significantly between local (78 percent) and nonlocal (90 percent) sources (table 3). An average survival of 84 percent for the two sources demonstrated that wildling red alder were successfully transplanted into this 3-year-old Douglas-fir plantation.

Growth.—Dg and average height 4 years after planting did not vary significantly between local and nonlocal sources (table 6). These initial results indicated no apparent advantage in using nonlocal red alder to reduce aboveground competition with associated Douglas-fir.

Volunteer Red Alder

Growth.—Most volunteer alder probably germinated in 1971 during the first growing season after site preparation and thus were 1 year older than the planted alder. These volunteer alder grew at an average density about half that of planted alder in regimes 1 and 2 (table 2). At plantation age 7, volunteer alder in regime 4 had a statistically significant greater Dg (23 percent) and average height (18 percent) than those of both sources of planted alder (table 6). This larger size can be explained by the 1-year difference in age and the lower density. Although fewer in number, these volunteer alder were probably more competitive because of their larger size. For example, the Douglas-fir:red alder height ratio at age 7 averaged 0.6 in regime 4 with volunteer alder as compared to 0.8 in regimes with planted alder.

Table 6—Average size of red alder at plantation age 7

Regime	Dg	Height
	mm	m
Douglas-fir/planted alder:		
1. Local alder	43a	5.0a
2. Nonlocal alder	38a	4.8a
Douglas-fir/volunteer alder:		
3. Alder cut at age 3	--	--
4. Alder cut at age 7	50b	5.8b
Differences among regime means	1/	1/

-- = not applicable.

1/ Values in same vertical column with different letter are significantly different ($P < 0.10$).

Alder Sprouts and Volunteers

Controlling alder density in Douglas-fir plantations may be difficult because of alder stump sprouts and volunteers. In this tractor-scarified study area, alder sprouts and volunteers were cut several times in unsuccessful attempts to keep regime 3 free of alder. Surplus alder were also cut in the other regimes at plantation age 7. Three years after cutting, average percentage of sprouting stumps ranged from 10 to 32 among the four regimes, but the means did not differ significantly (table 5). Average sprouting percentage (32) and average height (4.9 m) of the tallest sprout from each stump after 3 years were greatest from the few, unwanted alder in regime 3, probably because these sprouts were from younger trees that survived earlier cuttings.

Average height of the tallest, 3-year-old sprout per stump in regimes 1, 2 (planted alder), and 4 (volunteer) were the same. The associated Douglas-fir were taller than these alder sprouts and averaged between 5.8 and 6.5 m (fig. 2); thus, cutting surplus alder at age 7 years reduced the risk of upper crown abrasion but did not completely eliminate alder root competition or N contributions.

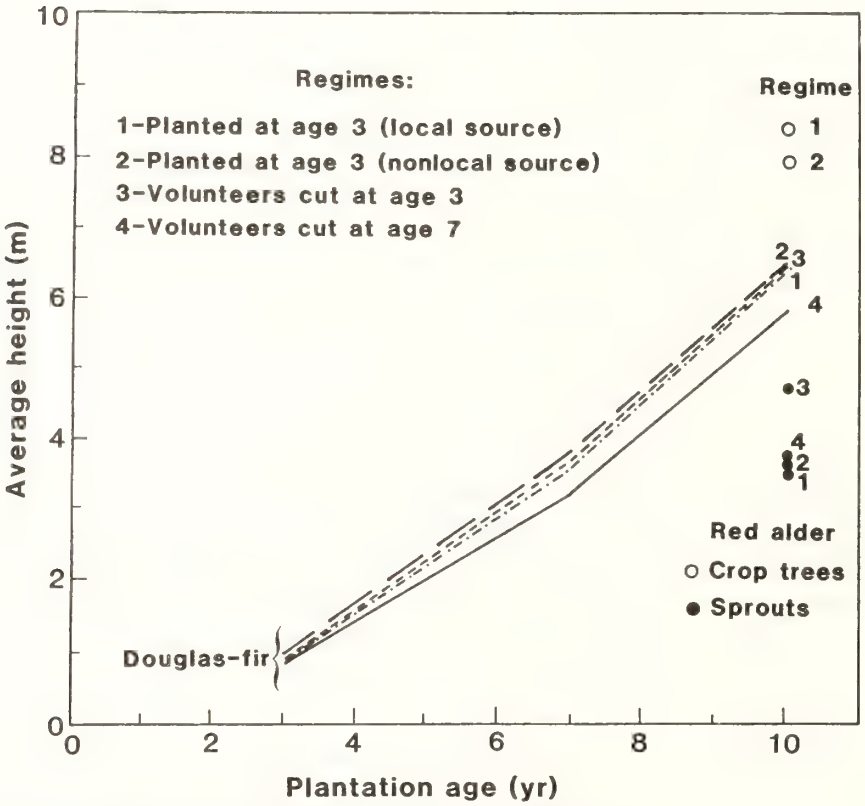

Figure 2.—Trend of average height of planted Douglas-fir and average height of crop trees and sprouts, both at plantation age 10 years, by regime.

Discussion

Local vs. Nonlocal Interplanted Alder (Question 1)

Our data indicated no apparent advantage in using nonlocal red alder to reduce aboveground competition with Douglas-fir at this location. Survival of both sources of planted alder was high and comparable (table 3).

Cole (1984) also documents good survival of red alder wildlings planted at three forest locations in Oregon; two of these locations were abandoned pastures. All locations were below 200 m elevation. Local sources of 1-year-old alder wildlings were transplanted at each location and herbaceous vegetation controlled by herbicide during the first 2 years after planting. These locations were selected to sample a transect of climates: the warm, dry climate of the Willamette Valley; the warm, moist climate of the mid-Coast Ranges; and the cool, moist climate of the coastal fog belt. Red alder survival in the 5-year period after planting was high at all locations. Survival averaged nearly 90 percent; practically all mortality occurred in the first year. Vigor of transplanted alder was reduced (1) by a late spring frost that top-killed most alder at the mid-Coast Ranges location, (2) by deer and elk browsing and rubbing at two locations, and (3) by low vigor and early leaf senescence at the coastal site that did not occur in volunteer alder.

We had anticipated that nonlocal, coastal alder would have lower survival and slower growth than a local source from near this 540-m elevation. Nonlocal alder seedlings from a source close to sea level that were interplanted in a 4-year-old Douglas-fir plantation at 600 m in the Wind River Experimental Forest were severely frosted the first autumn and spring after planting; yet local, volunteer alder were not damaged (Miller and Murray 1978). In contrast, our coastal source of red alder was not damaged by the below-freezing air temperatures that occur between November and April at the White River Tree Farm.

Average percentage of sprouting stumps and average height of the tallest sprout did not differ for the two alder sources. Moreover, the number and size of associated Douglas-fir through plantation age 10 provided no basis for preferring either alder source.

At this location with an average volunteer alder density of 1 120/ha and an average red alder:Douglas-fir density ratio of about 1:1, delayed cutting of volunteer alder until year 7 did not reduce the number of Douglas-fir available for crop tree selection. Although average height and Dg of Douglas-fir in the volunteer alder plots (regime 4) were about 10 percent less than those of Douglas-fir released at 3 instead of 7 years, our statistical analyses indicated that this difference was not significant.

Cutting Surplus Volunteer Alder (Question 2)

We believe that further delay of release would have reduced Douglas-fir survival and increased damage of crop trees through mechanical abrasion of buds and twigs. For example, our height class frequency data showed that regimes 3 and 4 had similar ranges of Douglas-fir heights, but the delayed release plots (regime 4) had a larger proportion of trees in the shorter height classes (46 vs. 31 percent were shorter than 4 m at age 7). As expected, these short, spindly trees were typically located under clumps of alder with closed canopy.

For naturally seeded red alder stands, and at elevations below 150 m on Douglas-fir sites I and II in southwest Washington, Dougherty[3/] projected crown closure at 2 to 6 years from seed depending on alder density. For 1 250 alder/ha, he projected canopy closure at 6 years. Severe competition for light between alder and associated Douglas-fir would start at that time. Considering the lower site quality and lower alder density in our regime 4, one could reasonably expect crown closure and strong competition between Douglas-fir and red alder to occur after 6 years at the White River site.

Based on our data from White River and Dougherty's projections for higher site lands, alder control can safely be delayed on most Douglas-fir site III or poorer land until 6 to 8 years after planting Douglas-fir, if alder density is less than 1 250/ha. This could permit combining alder control with precommercial thinning of Douglas-fir and, thus, eliminate earlier spraying or mechanical release. A specific number of well-spaced alder could be left during the thinning operation to provide nitrogen.

Size and Occurrence of Sprouts (Question 3)

Three years after the release cutting in February at plantation age 7, from 0 to 46 percent of the alder stumps on the 12 plots had sprouts. Treatment means ranged from 10 to 32 percent, but these did not differ significantly. The most frequent sprouting and the tallest sprouts occurred in "alder-free" regime 3. Because of two earlier attempts to eradicate alder from this regime, alder seedlings cut at plantation age 7 were undoubtedly younger than those of the other regimes. Mineral soil exposed during scarification undoubtedly favored continued natural regeneration by providing favorable conditions for alder germination and survival (Kenady 1978, Newton and others 1968).

Recent research (Harrington 1984) shows that red alder sprouting is most vigorous in 1- to 2-year-old trees and less so in trees 3 to 10 years old at the time of cutting. Because cutting red alder at an early age leaves a stump conducive to sprouting, mechanical release of Douglas-fir from competing alder could be delayed until Douglas-fir crop trees are clearly threatened. Stump sprouting can also be minimized by cutting during the growing season (vs. our cutting before the growing season) and by leaving a low stump of less than 10 cm (Harrington 1984).

Without further control, vigorous alder sprouts could again overtop Douglas-fir (a negative effect) yet provide additional N-rich organic matter (a positive effect). To obtain a desirable balance between the positive and negative effects of red alder sprouts or seedlings in Douglas-fir plantations, silviculturists must systematically control alder density, especially in the first decade.

3/ Unpublished report, 1980, "Relationship of Alder Stand Characteristics to the Rate of Crown Closure," by P.M. Dougherty, Weyerhaeuser Company, Western Forestry Research Center, Centralia, WA. Report is on file at the Forestry Sciences Laboratory, 3625 93d Avenue, S.W., Olympia, WA 98502.

Among the regimes that we tested, regime 3 probably had the least potential for influencing Douglas-fir— either positively or negatively. Although regime 3 was designed to be a control, it was not free of alder because (1) this regime probably had a similar number of N-fixing alder volunteers through age 3 as the other regimes (table 3) and (2) alder sprouts and additional volunteers remained despite repeated efforts to maintain an alder-free condition (tables 2 and 5). Both facts compromised regime 3 as a control treatment. Despite a lesser alder component, average 7- and 10-year height and diameter of Douglas-fir in regime 3 did not differ from height and diameter in the remaining regimes that had greater densities of alder. These results have several possible explanations:

1. Available nitrogen may not limit growth of Douglas-fir at this site—at least in the early stage of plantation development.

2. Retaining alder for more than 3 years after planting Douglas-fir may have no additional or measurable impact at this location.

3. The negative, competitive effects of red alder may have offset the positive effects of N additions after age 3 at this site.

Future measurements should be enlightening for several reasons. First, the plantation's need for nitrogen is likely to peak about the time of canopy closure; thus, N shortages are more likely to limit growth in the immediate future in regime 3. Second, the positive effects of the alder in regimes 1 and 2 (with 50, 100, or 200 alder/ha) should become evident. Finally, we shall have the opportunity to compare the growth of Douglas-fir fertilized with urea (regime 4) to that of Douglas-fir with a specified number of admixed alder.

Conclusions

1. Several conclusions can be drawn from this study: Both a local and a nonlocal source of wildling red alder were successfully interplanted into this 3-year-old Douglas-fir plantation. Survival percentage 4 years after planting did not vary between local and nonlocal sources of alder, and neither Dg nor average height differed between the two sources. Our data indicated no apparent advantage in using nonlocal red alder to reduce aboveground competition with Douglas-fir at this location.

2. Seven-year-old, volunteer alder, which were 1 year older and growing at 50-percent lower density than the interplanted alder, were an average of 23 percent larger in diameter and 18 percent taller than interplanted alder. Cutting these volunteer alder at plantation age 7, instead of at age 3, did not affect Douglas-fir survival or average size. Further delay probably would have eliminated or damaged some crop trees.

3. Alder competition at average densities of 1 100-2 200 alder/ha did not affect Douglas-fir survival or average tree size at plantation age 7 years; average number, Dq, and height of planted Douglas-fir in the three regimes with competing alder (both planted and volunteer) were not different from those in regime 3 with only a few, unwanted alder seedlings and sprouts.

4. When red alder densities are lower than about 1 250/ha, silviculturists can delay alder control on site III or lower until 6 to 8 years after planting Douglas-fir. This will reduce sprouting and permit combining complete or partial control of alder with early precommercial thinning. Thus, earlier chemical or mechanical release can be eliminated.

5. Three years after cutting alder in February (at plantation age 7 years), 10 to 32 percent of alder stumps in the regimes we studied had sprouts. Average height of the tallest sprout per stump ranged from 3.7 to 4.9 m among the four regimes (vs. 5.8 to 6.5 m for associated Douglas-fir). Without control, these sprouts may provide future positive (N-addition) or negative (crown competition) effects. To further minimize sprouting, alder should be cut close to the ground and cut during the growing season.

6. To obtain a desirable balance between positive and negative effects of red alder in Douglas-fir plantations, control of alder density should be delayed until the upper crown of Douglas-fir crop trees is in contact with nearby alder. Periodic observations, especially during the first decade after planting, are necessary to ensure timely control.

7. Because of some recurring alder sprouts and volunteers, our control regime was not truly free of alder. Our finding no difference in average size of planted Douglas-fir in this regime vs. the others is, therefore, not a pure demonstration that alder failed to affect growth of Douglas-fir. Measurable positive benefits of N-fixation by alder are most likely at future crown closure when demand for this nutrient is greater.

Acknowledgments

We thank the following for their help: Weyerhaeuser Co. for providing the study area and financial and technical support; John Hazard and Tim Max for guidance in experimental design and analysis; and Jim Wilcox for statistical analyses.

English Equivalents

1 centimeter (cm) = 0.3937 inch
1 meter (m) = 3.2808 feet
1 hectare (ha) = 2.4711 acres
1 kilogram (kg) = 2.2046 pounds

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Murray, Marshall D.; Miller, Richard E. Early survival and growth of planted Douglas-fir with red alder in four mixed regimes. Res. Pap. PNW-366. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 13 p.

To quantify between-species interactions, we measured and compared survival and growth of planted Douglas-fir and associated planted and volunteer red alder at a location on the west side of the Cascade Range in Washington. The planted alder were wildlings dug either from a nearby area or from a distant, coastal site and interplanted into a 3-year-old Douglas-fir plantation. The volunteer alder became established in year 1; these were cut at year 3 or 7 depending on the regime tested

The data indicated no apparent advantage in using nonlocal red alder to reduce aboveground competition with Douglas-fir at this location. Survival of both sources of interplanted alder was high and the average diameter and height were similar through plantation age 10. Retaining about 1 100 volunteer alder per hectare (445/acre) through plantation age 7 had no measurable positive or negative effect on the associated Douglas-fir.

When alder densities are less than about 1 250/ha (500/acre), silviculturists can safely delay alder control on most average or below-average site quality land until 6 to 8 years after planting Douglas-fir. This reduces alder sprouting and permits combining complete or partial control of alder with precommercial thinning of associated Douglas-fir. To ensure timely control, periodic observations of Douglas-fir red alder mixtures are necessary, however.

Keywords: Silvicultural systems, mixed stands, competition (plant), nitrogen fixation, Douglas-fir, *Pseudotsuga menziesii*, red alder, *Alnus Rubra*

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Radial Growth of Grand Fir and Douglas-Fir 10 Years After Defoliation by the Douglas-Fir Tussock Moth in the Blue Mountains Outbreak

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Abstract

Wickman, Boyd E. Radial growth of grand fir and Douglas-fir 10 years after defoliation by the Douglas-fir tussock moth in the Blue Mountains outbreak. Res. Pap. PNW-367. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 11 p.

Radial-growth recovery related to amount of tree defoliation was measured 10 years after a severe outbreak of Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough). For the period 1978-82, growth of grand fir surpassed and was significantly greater than in the preoutbreak period, 1968-72. Douglas-fir growth during the postoutbreak period showed similar patterns, but it was not significantly different from preoutbreak growth for every defoliation class. Growth of undefoliated trees was also greater during the postoutbreak period, indicating that above-normal precipitation aided tree recovery and masked the thinning effect of tree mortality.

Keywords: Increment (radial), insect outbreaks, Douglas-fir tussock moth, grand fir, Douglas-fir, Blue Mountains, Oregon, Washington.

Summary

Radial growth of individual trees was related to degree of defoliation 10 years after an outbreak of Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough). Study plots located in the Blue Mountains of Oregon and Washington during the outbreak in 1972 and 1973 were used to study various forms of tree damage. Trees on the same plots were measured in 1983 to determine growth recovery 10 years after the outbreak.

Increment cores were taken from every dominant and codominant grand fir (*Abies grandis* (Doug. ex D. Don) Lindl.) and Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) on the plots; a sample of nonhost trees was also cored. Nondefoliated host trees were cored from each of five check areas contiguous with the outbreak. Growth rates were compared for individual tree-defoliation classes between the preoutbreak and postoutbreak periods by using regression analysis and analysis of covariance to test for differences among these linear relations.

Growth recovery since the outbreak brought average radial growth to rates higher than those just before the outbreak for most grand fir defoliation classes. Growth recovery for Douglas-fir was similar, but not as pronounced. The difference between 5-year preoutbreak (1968-72) and 5-year postoutbreak (1978-82) growth was significant for all grand fir defoliation classes except the 90-percent class. For Douglas-fir, postoutbreak growth significantly surpassed the preoutbreak growth for the 25-, 50-, and 75-percent classes. Growth recovery from 1978-82 was apparently not strongly related to degree of defoliation. Above-average annual precipitation during the postoutbreak period caused all classes of trees—defoliated, nondefoliated, and nonhost—to respond positively, apparently masking growth differences caused by defoliation. These defoliated trees will be measured again in 1988; this remeasurement may reveal growth relations that have not yet become evident.

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Introduction

The Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough) is an important defoliator of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and true fir (*Abies* spp.) in western North America. Periodic outbreaks have caused severe timber losses. Tree mortality and top-kill account for most of the loss (Wickman 1978a), but reduced radial growth may add significantly to the damage (Wickman and others 1980).

The decline in growth of white fir (*Abies concolor* (Gord. & Glend.) Lindl.) caused by tussock moth defoliation is one of the most drastic on record for a forest defoliator (Koerber and Wickman 1970). The radial-growth configurations are so distinctive that old outbreaks can be easily identified from increment cores or disks cut from host trees (Wickman 1963, Wickman 1986, Brubaker 1978).

White fir, grand fir (*Abies grandis* (Doug. ex Don) Lindl.), and Douglas-fir defoliated by tussock moth in California, Oregon, and Washington have shown severe radial-increment loss during and immediately after defoliation (Wickman 1963, 1978b; Wickman and others 1980). The growth reduction was also related to degree of defoliation: trees defoliated 75 to 90 percent had more than double the growth reduction of trees defoliated less than 25 percent. Growth recovery was usually not complete until 4 or 5 years after defoliation. Stand conditions and tree growth were studied 10 years after a severe outbreak in California (Wickman 1978b). In that study, white fir recovery—as evidenced by increased radial growth—was well established 10 years after severe defoliation. Growth of both host and nonhost trees in the defoliated area surpassed preoutbreak rates; the reverse was true for nearby nondefoliated host trees.

An extensive outbreak in the Blue Mountains of Oregon and Washington in 1972-74 offered the opportunity to study tree damage resulting from defoliation by extremely dense tussock moth populations. The objective of studies begun in 1972 was to use defoliation intensity in 1972 and 1973 as a predictor of tree damage during and after the outbreak. Three important forms of damage—tree mortality, top-kill, and radial-growth reduction—have been summarized from these studies (Wickman 1978a, Wickman and others 1980). The three forms of damage have also been mathematically represented in the tussock moth outbreak and stand prognosis models (Overton and Colbert 1978, Monserud and Crookston 1982).

This study related radial growth of individual trees 10 years after the outbreak to degree of defoliation. The information can be used for mathematical representation in the tussock moth outbreak model and for updating the stand-prognosis model.

Methods

Plot Location and Defoliation Classes

More than 300 1/50th-acre plots were established in conjunction with 22 tussock moth population study areas (Mason 1976) in the Blue Mountains to study the effects of defoliation (Wickman 1978a). The area consisted of a 100-km transect of a tussock moth outbreak on the Umatilla and Wallowa-Whitman National Forests and included four additional, severely defoliated areas not included in the population study. Defoliation of each plot tree was estimated in seven classes immediately after the year of most intense defoliation (1972 or 1973). Defoliation classes were based on the percentage of crown length totally defoliated, as described in Wickman (1978a).

Sampling Techniques

Clusters of 10 to 15 damage plots were systematically gridded at each of the population study points and at some additional, severely defoliated areas in the Wenaha-Tucannon Wilderness. Every tree over 1-in d.b.h. on the 1/50th-acre circular plots was tagged and measured, and its defoliation was estimated. Complete information on plot establishment and tree measurements has been published (Wickman 1978a).

From July 15 to September 15, 1983, increment cores were taken from every dominant and codominant grand fir and Douglas-fir on the plots. These were the same trees that were cored in 1978 (less a few logged or killed trees). In addition, one dominant or codominant nonhost tree (if present) was cored on each plot. Twenty-one mature ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) were sampled from a pine stand on a dry ridge (sensitive site) in the outbreak area to compare general tree-growth patterns to climate (Fritts 1976). Nondefoliated host trees were cored from each of five check areas contiguous with the outbreak. Controls were 1 to 8 km from defoliated stands.

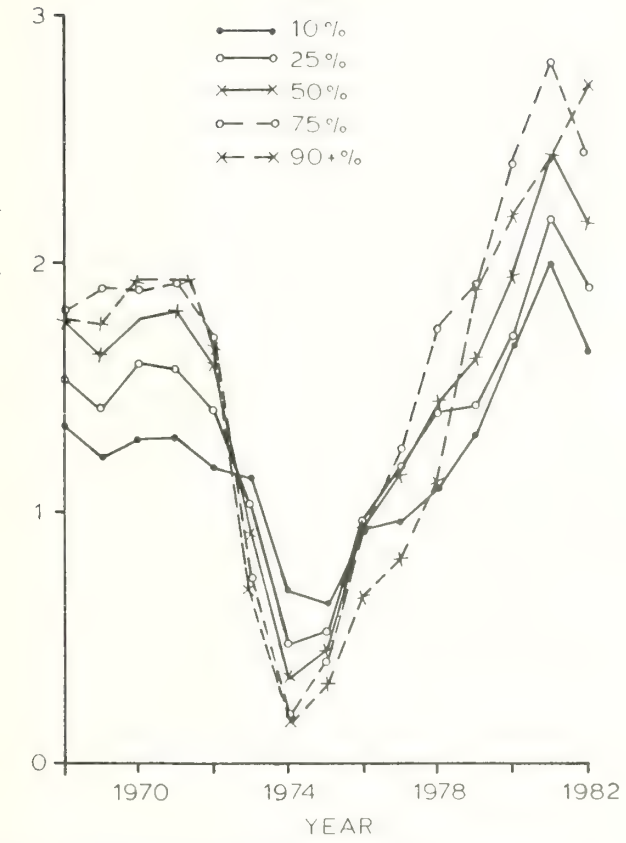
Two increment cores, including at least the last 20 years of growth, were taken from each tree at breast height. The cores were from two quadrants at 90 degrees, usually the north and west if possible, as suggested by Fritts (1976). Cores were glued to blocks of wood and sanded smooth.

A Bannister incremental-measuring machine coupled to an Apple II computer was used to measure annual increment to the nearest 0.01 mm (Stokes and Smiley 1968).[1] Measurements were tabulated and stored on discs by the Apple II and analyzed later on a mainframe computer. Because some cores were taken before 1983 growth was complete, growth measurements only through 1982 were used.

Analysis

Growth patterns for the 10-year outbreak and postoutbreak period (1973-82) were obtained from the following sets of trees: defoliated grand fir and Douglas-fir on the plots; nonhost trees on the plots; and nondefoliated hosts, grand fir, and Douglas-fir near the plots. Average radial growth was graphed by individual tree-defoliation classes for grand fir and Douglas-fir (figs. 1, 2). Growth averages for the years 1968-78 are the averages obtained from 1978 measurements (Wickman and others 1980). Average annual growth from 1979 to 1982 was added to each of the defoliation-class curves used in that earlier report.

[1]Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.



gure 1—Average radial growth of grand fir tree-defoliation asses, 1968-82, in the Blue Mountains, Oregon and Vashington.

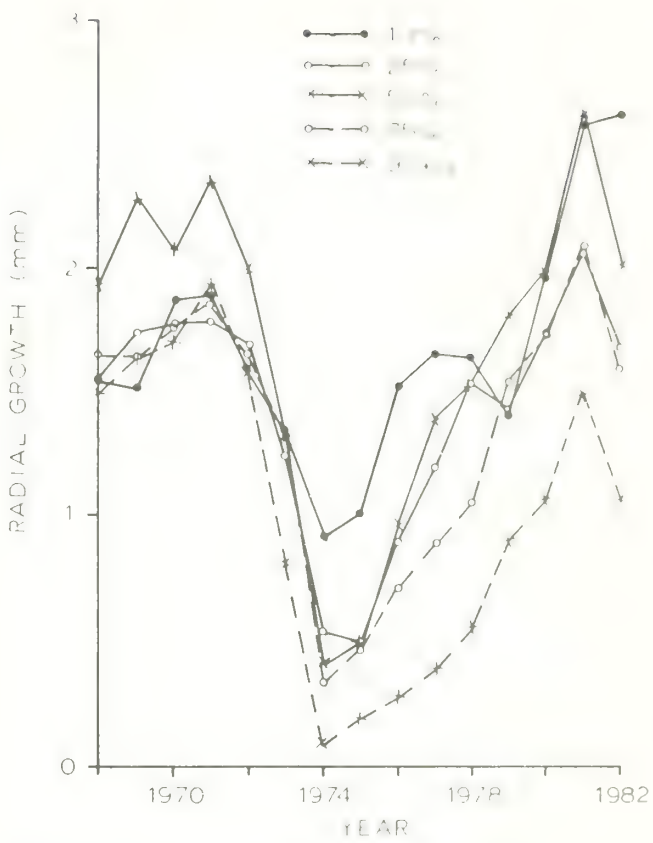


Figure 2—Average radial growth of Douglas-fir by tree-defoliation classes, 1968-82, in the Blue Mountains, Oregon and Washington.

Comparisons of average annual radial growth for defoliated host and nondefoliated host were made for five preoutbreak years (1968-72), the outbreak and recovery period (1973-77), and five postoutbreak years (1978-82). A paired t-test was used to compare preoutbreak with postoutbreak mean annual growth of individual trees within each of the two tree classes. This analysis indicates whether postoutbreak growth is significantly greater than preoutbreak growth in the defoliated-tree class.

Growth rates for individual tree-defoliation classes between the preoutbreak and postoutbreak periods were compared using regression analysis and analysis of covariance to test for differences among these linear relations. Independent random sampling of trees was assumed even though trees occurred in groups by plot clusters.

Results and Discussion

Both grand fir and Douglas-fir exhibited continuous improvement in growth until 1981. In 1982, all classes declined except the 90-percent class for grand fir and the 10-percent class for Douglas-fir, which were still on an upward trend. Growth recovery since the outbreak raised average radial growth to rates higher than those just before the outbreak for most grand fir defoliation classes (fig. 1). Growth of Douglas-fir defoliated 90 percent had not reached preoutbreak rates by 1981, but small sample size (seven trees) makes this curve suspect (fig. 2). The growth recovery for the three most severely defoliated classes of grand fir was greater than the lighter defoliation classes (fig. 1). Because most of the trees in these classes occurred in areas that also sustained severe tree mortality, the resulting decrease in stocking may have improved radial growth. The growth trend increased annually from 1975, coinciding with the pattern of average annual precipitation recorded at a nearby weather station (fig. 3) until 1982, when growth inexplicably declined for most defoliation classes.

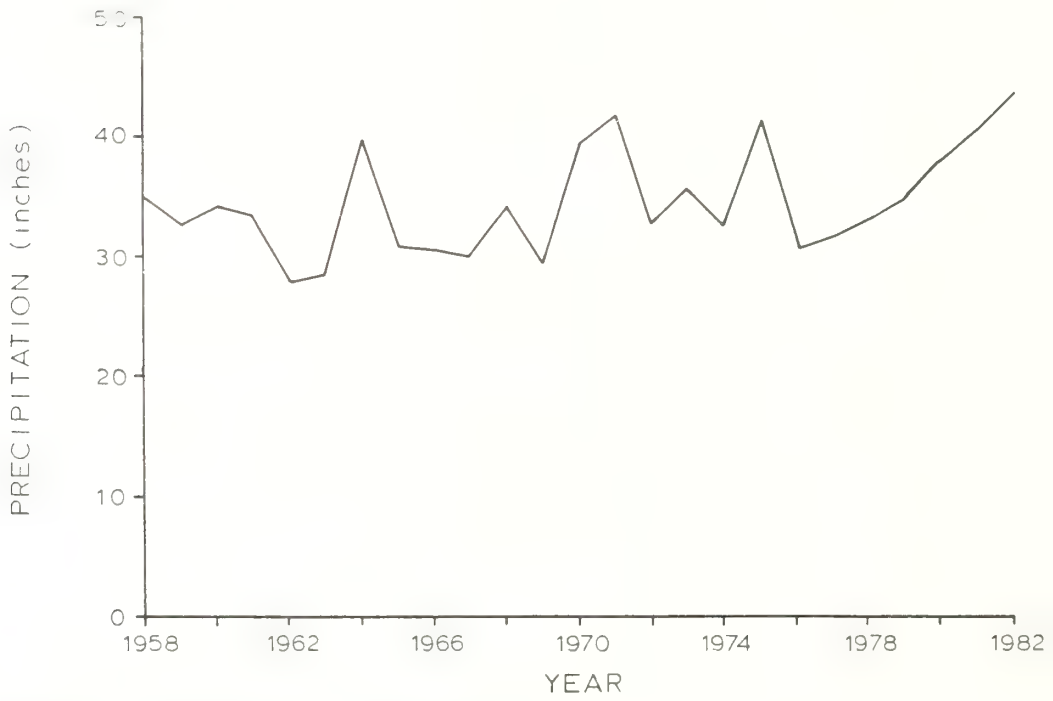


Figure 3—Annual precipitation at Meacham, Oregon adjusted from Gibbon, Oregon, annual precipitation.

The sample of 21 ponderosa pine from a pure pine stand on a dry ridge surrounded by defoliated stands provided additional insight because pines are more sensitive than fir to changes in soil moisture (Fritts 1976). The year (1974) of greatest pine-growth depression (fig. 4) also coincided with the year of greatest growth reduction of defoliated fir, indicating that the unfavorable environment increased the effects of defoliation (Wickman and others 1980). In 1976, pine exhibited greatly increased growth, as did other species of nonhost trees (fig. 5). Precipitation thus played a positive role in the recovery of defoliated trees for at least 2 years after the outbreak.

During 1977-82, the sensitive pine did not always respond positively to increased precipitation (for example, in 1979), nor did other nonhost trees on the sample plots (fig. 5). The reason for this anomaly is not known, but it does illustrate the variability often found in relating tree growth to precipitation. Annual precipitation, for instance, may not indicate available moisture during the growing season.

Figure 4—Average annual diameter growth of ponderosa pine from dry ridge surrounded by defoliated stands in the Blue Mountains, Oregon and Washington.

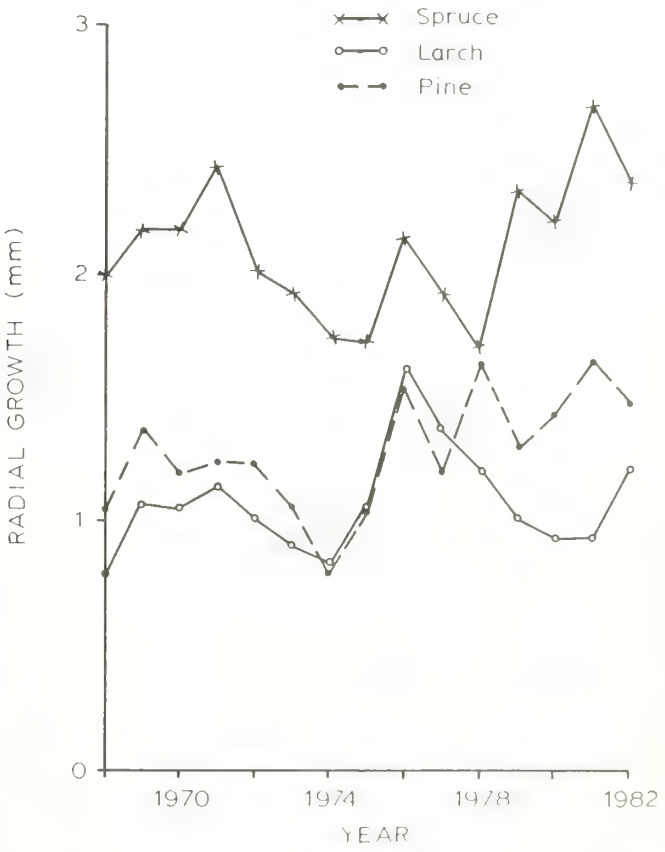


Figure 5—Average radial growth of nonhost trees, 1968-82, in the Blue Mountains, Oregon and Washington.

Growth rates declined in 1982 in all but two defoliation classes. This 1982 decline also occurred in the nonhost species on the plots, except for western larch (*Larix occidentalis* Nutt.) on which growth increased after 4 years of decline (fig. 5). Nondefoliated host near the plots had the same general pattern of growth as defoliated host trees for the period 1978-82, only the growth was greater (fig. 6). This response likely resulted from higher precipitation during the recovery period and because most of the nondefoliated trees were from better sites, such as canyon bottoms (Wickman and others 1980).

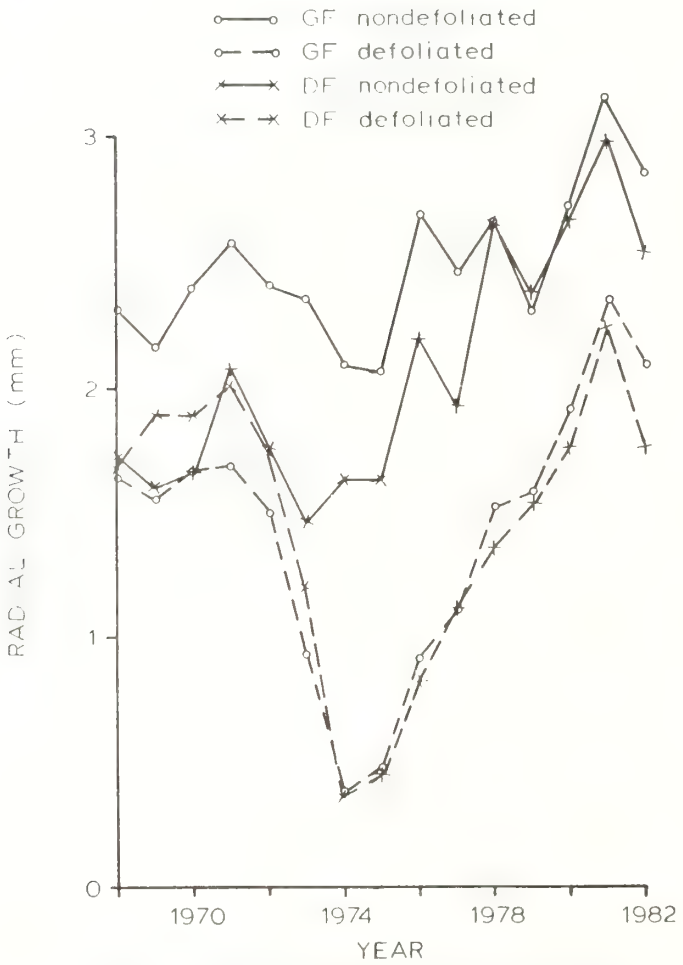


Figure 6—Average radial growth of all defoliated and nondefoliated grand fir and Douglas-fir in the Blue Mountains, Oregon and Washington.

Growth between the preoutbreak and postoutbreak periods of both defoliated and nondefoliated hosts responded similarly (table 1). Above-average precipitation probably played an important role in the similar growth patterns of both tree classes in the postoutbreak period. The effects of adequate precipitation masked whatever enhanced growth might have occurred from reduced competition for resources in the defoliated areas. Postoutbreak growth of defoliated trees was greater ($p < = 0.001$) than preoutbreak growth. Defoliated trees demonstrated good recovery, but not at the rate found in California outbreaks (Wickman 1978b, Wickman 1980).

Table 1—Comparisons of average annual growth of defoliated and nondefoliated trees during preoutbreak (1968-72), outbreak (1973-77), and postoutbreak (1978-82) periods, using a paired t-test in the Blue Mountains, Oregon and Washington

	Means of radial growth		
Tree class	Preoutbreak	Outbreak	Postoutbreak
		Millimeters	
Defoliated host	1.68	0.80	1.90
Nondefoliated host	2.61	2.59	2.84

Preoutbreak with postoutbreak:	t-value	Significance
Defoliated host	5.19	0.001
Nondefoliated host	2.75	.01

The difference between 5-year preoutbreak (1968-72) and 5-year postoutbreak (1978-82) was significant ($p < = 0.01$) for all grand fir defoliation classes except the 90-percent class ($p < = 0.05$) (table 2, fig. 7). For Douglas-fir, the postoutbreak growth surpassed the preoutbreak growth ($p < = 0.01$) for 25-, 50-, and 75-percent tree-defoliation classes. The 10- and 90-percent classes showed no significant increase of postoutbreak growth (table 2, fig. 8). Thus, growth recovery from 1978 to 1982 was apparently not strongly related to degree of defoliation.

Table 2—Regressions of preoutbreak (1968-72), x, and postoutbreak (1978-82), y, growth for host trees by defoliation class, Blue Mountains, Oregon and Washington

Tree class	n	a	b	r^2	P
Grand fir:					
Nondefoliated	42	0.968	0.707	0.665	0.01
Defoliated (percent)—					
10	29	.444	.876	.548	.01
25	142	.384	.880	.434	.01
50	149	.817	.657	.236	.01
75	55	.888	.737	.319	.01
90+	13	−.009	1.165	.315	.05
Douglas-fir:					
Nondefoliated	30	.428	.953	.477	.01
Defoliated (percent)—					
10	3	−.220	1.174	.587	NS
25	12	.395	.831	.654	.01
50	19	.300	.762	.568	.01
75	12	−.177	1.185	.629	.01
90+	5	−1.223	1.254	.530	NS

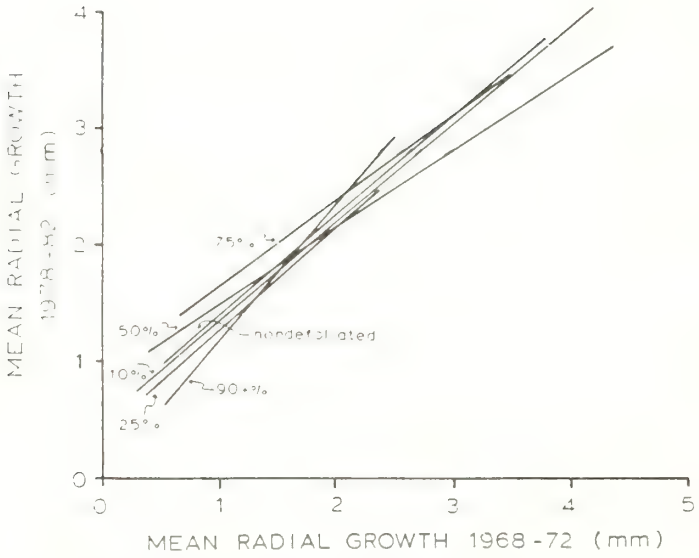


Figure 7—Radial growth of grand fir by percentage of defoliation, comparing preoutbreak with postoutbreak periods in the Blue Mountains, Oregon and Washington.

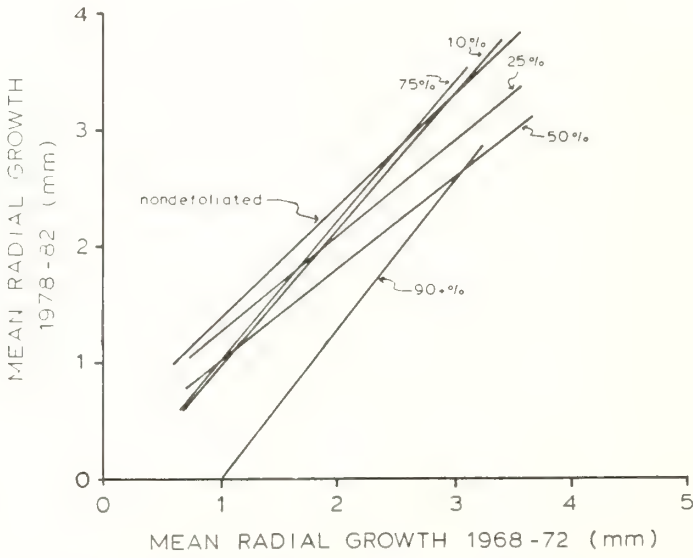


Figure 8—Radial growth of Douglas-fir by percentage of defoliation, comparing preoutbreak with postoutbreak periods in the Blue Mountains, Oregon and Washington.

Above-average annual precipitation caused all classes of trees—defoliated, nondefoliated, and nonhost—to respond positively, masking subtle differences caused by other factors like defoliation (tables 1-3). This response seemed consistent for all years except 1982, when the situation was reversed for unknown reasons. These results were not as positive as those from data collected in California, where 10 years after a tussock moth outbreak, defoliated trees exhibited significantly greater growth than nearby nondefoliated hosts (Wickman 1978b). Precipitation there was on a downward trend during a similar 5-year postoutbreak period.

The vagaries of tree-growth response in different outbreak areas and years point out the problem of using radial increment as a consistent indicator of a forest's response to defoliation and subsequent recovery. Effects of site, nutrient cycling, competition, and local environmental conditions all contribute to tree growth, and any one factor may tend to mask some of the other influences. Even one factor, such as precipitation, can have different effects on growth depending on timing and distribution. Such relations are still not clearly understood. Pest managers should be cautious in using radial growth data for justifying management practices, understanding that short-term tree-growth responses to defoliation may not always relate strongly to long-term stand development. Measurements of these defoliated trees scheduled for 1988 may reveal growth relations not yet evident.

Table 3—Average annual radial growth of grand fir and Douglas-fir during preoutbreak (1968-72), outbreak (1973-77), and postoutbreak (1978-82) periods, Blue Mountains, Oregon and Washington

Tree class	Pre-outbreak (1968-72)	Outbreak (1973-77)	Post-outbreak (1978-82)
		Millimeters	
Grand fir:			
Nondefoliated	2.67	2.62	2.85
Defoliated (percent)—			
10	1.46	.87	1.72
25	1.51	.83	1.71
50	1.74	.75	1.96
75	1.82	.68	2.24
90 +	1.76	.53	2.05
Douglas-fir:			
Nondefoliated	2.52	2.54	2.83
Defoliated (percent)—			
10	1.99	1.27	2.12
25	1.67	.79	1.79
50	2.18	.88	1.96
75	1.81	.74	1.97
90 +	1.71	.35	0.92

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Radial-growth recovery related to amount of tree defoliation was measured 10 years after a severe outbreak of Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough). For the period 1978-82, growth of grand fir surpassed and was significantly greater than the preoutbreak period 1968-72. Douglas-fir growth during the postoutbreak period showed similar patterns, but it was not significantly different from preoutbreak growth for every defoliation class. Growth of undefoliated trees was also greater during the postoutbreak period, indicating that above-normal precipitation aided tree recovery and masked the thinning effect of tree mortality.

Keywords: Increment (radial), insect outbreaks, Douglas-fir tussock moth, grand fir, Douglas-fir, Blue Mountains, Oregon, Washington.

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September 1986

VIRGINIA'S Forest Products Industry: Performance and Contribution to the State's Economy, 1970 to 1980

CLEMSON UNIVERSITY
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PUBLIC DOCUMENTS

Con H Schallau, Wilbur R. Maki, Bennett B. Foster, and Clair H. Redmond

Abbreviations

States

AL	Alabama
AR	Arkansas
FL	Florida
GA	Georgia
KY	Kentucky
LA	Louisiana
MS	Mississippi
NC	North Carolina
OK	Oklahoma
SC	South Carolina
TN	Tennessee
TX	Texas
VA	Virginia
SO	South
US	United States

Industries

FPI	Forest Products Industry
LWP	Lumber and Wood Products
PAP	Paper and Allied Products
WF	Wood Furniture

Authors

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Abstract

Schallau, Con H; Maki, Wilbur R.; Foster, Bennett B.; Redmond, Clair H. Virgina's forest products industry: performance and contribution to the State's economy, 1970 to 1980. Res. Pap. PNW-368. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

Employment and earnings in Virginia's forest products industry, like those of most Southern States, increased between 1970 and 1980. Furthermore, Virginia's share of the Nation's forest products employment and earnings increased during this period. In 1980, the wood furniture segment accounted for the largest share of the industry's employment, but paper and allied products accounted for the largest share of earnings. In 1977, pulp and allied products had higher productivity than either lumber and wood products or wood furniture.

Keywords: Forest products industries, economics (forest products industries), employment (forest products industries), Virginia.

Preface

This report briefly describes Virginia's forest products industry—its composition, location, evolution, and relation to economic activity elsewhere in the State, the South, and the Nation.

Estimates of employment and earnings shown in this report were derived from U.S. Department of Commerce data. All references to dollar amounts are in constant 1977 dollars.

This is one in a series of reports for each of the 13 Southern States. These reports are companions to an analysis of the changing roles of the forest products industries of the South and the Pacific Northwest.

Highlights

- In 1980, Federal military and civilian employment accounted for more than 60 percent of Virginia's economic base. This high degree of dependency on the Federal Government reflects the State's proximity to Washington, DC, and several military installations within its borders. The forest products industry was the second largest manufacturing segment of the State's economic base.

- The forest products industry accounted for over one-third of the economic base of several counties in central Virginia. Almost one-half of the counties rely on the forest products industry for at least 10 percent of their economic base employment. The importance of the forest products industry increased in many of these areas between 1970 and 1980.

- Growth in employment in Virginia's forest products industry was more than twice the average national rate for this industry. As a result, the State had nearly 2,300 more employees than it would have had if the industry had grown at the average rate.

- In 1980, wood furniture had the largest share of the approximately 60,000 workers employed by Virginia's forest products industry; paper and allied products accounted for the largest share of earnings.

- In 1977, Virginia was fifth among the 13 Southern States in terms of value added by the forest products industry. The State's increase in value added between 1972 and 1977 was, however, less than for all but two Southern States.

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1 The State's Work Force
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5 Composition of the State's Forest Products Industry
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The Forest Products Economy of Virginia

The State's Work Force

Virginia's estimated full- and part-time work force in 1980 was comprised of an estimated 2.6 million employees and proprietors (see appendix 1, table 1, for sources of employment and earnings data). Virginia's work force grew considerably faster between 1970 and 1980 than did the national average (29.1 versus 22.3 percent). Total earnings—wage and salary payments and proprietorial income—also grew faster than the national average. Measured in constant 1977 dollars, the State's earnings increased by 37.0 percent compared with 27.4 percent for the Nation. As can be seen in the following tabulation, services, manufacturing, retail trade, and State and local government were the State's four largest employer categories:

	Percent of total employment, 1980	
Employers	**Virginia**	**U.S.**
Major industries:		
Services	17.44	18.22
Manufacturing (including the forest products industry[1/])	15.85	19.15
Retail trade	13.23	14.18
State and local government	12.78	12.56
Federal military	6.68	2.30
Federal civilian	6.24	2.81
Self-employed	5.39	6.58
Construction	5.01	4.08
Transportation, communication, and public utilities	4.40	4.84
Finance, insurance, and real estate	4.21	4.95
Subtotal	91.23	89.67
All other industries	8.77	10.33
Total	100.00	100.00

[1/]The forest products industry is comprised of (1) lumber and wood products (SIC 24), except mobile homes (SIC 2451); (2) wood furniture manufacturing (SIC 2511, 2512, 2517, 2521, 2541); and (3) paper and allied products (SIC 26).

Components of the State's Economic Base

Along with total employment there is another and perhaps more important way to judge an industry's contribution to Virginia's economy. For the State's economy to grow and develop, it must attract new dollars so residents can buy goods and services produced elsewhere. The industries that export products and services beyond local boundaries (that is, to elsewhere in the State, to other States, and to the world) and bring in new dollars constitute the area's economic base. Generally speaking, most manufacturing employment is classified as "economic base" (or "basic"), whereas service or residentiary employment (for example, barber shops, realty firms, schools, and local government) is primarily geared to producing for local needs. Some services may, however, be basic. For example, Federal military provides national defense for all the Nation's citizens, and taxpayers outside Virginia provide financial support for this activity.

Residentiary employment is supported by the economic base. Money flowing in provides income for wage earners and entrepreneurs to spend on locally purchased goods and services. In most cases, the economic growth of a region is dependent on the success of its economic base.

We used excess employment and excess earnings techniques to identify the industries that comprise Virginia's (or the sub-State district's) economic base. This approach accepts the national distribution of employment among industries as a norm. Any industry with employment or earnings in excess of this norm is considered to be producing for export markets outside the State (or a sub-State district) and is part of Virginia's economic base. The percentage of Virginia's excess employment and earnings served as an indicator of the State's dependency on a particular industry for generating new dollars from outside the State (table 2 shows how excess employment and industry-dependency indicators for Virginia were calculated). A particular industry may be basic at the local level but not at the State level.

In 1980, 10 industries accounted for 99.02 percent of the State's basic employment and 94.18 percent of basic earnings. Federal military and civilian employment—heavily dependent on governmental activities in the Washington, DC, area—accounts for a major share of the State's basic employment and earnings. In 1980, the forest products industry was the fifth largest component of the economic base in terms of employment and sixth in terms of earnings.

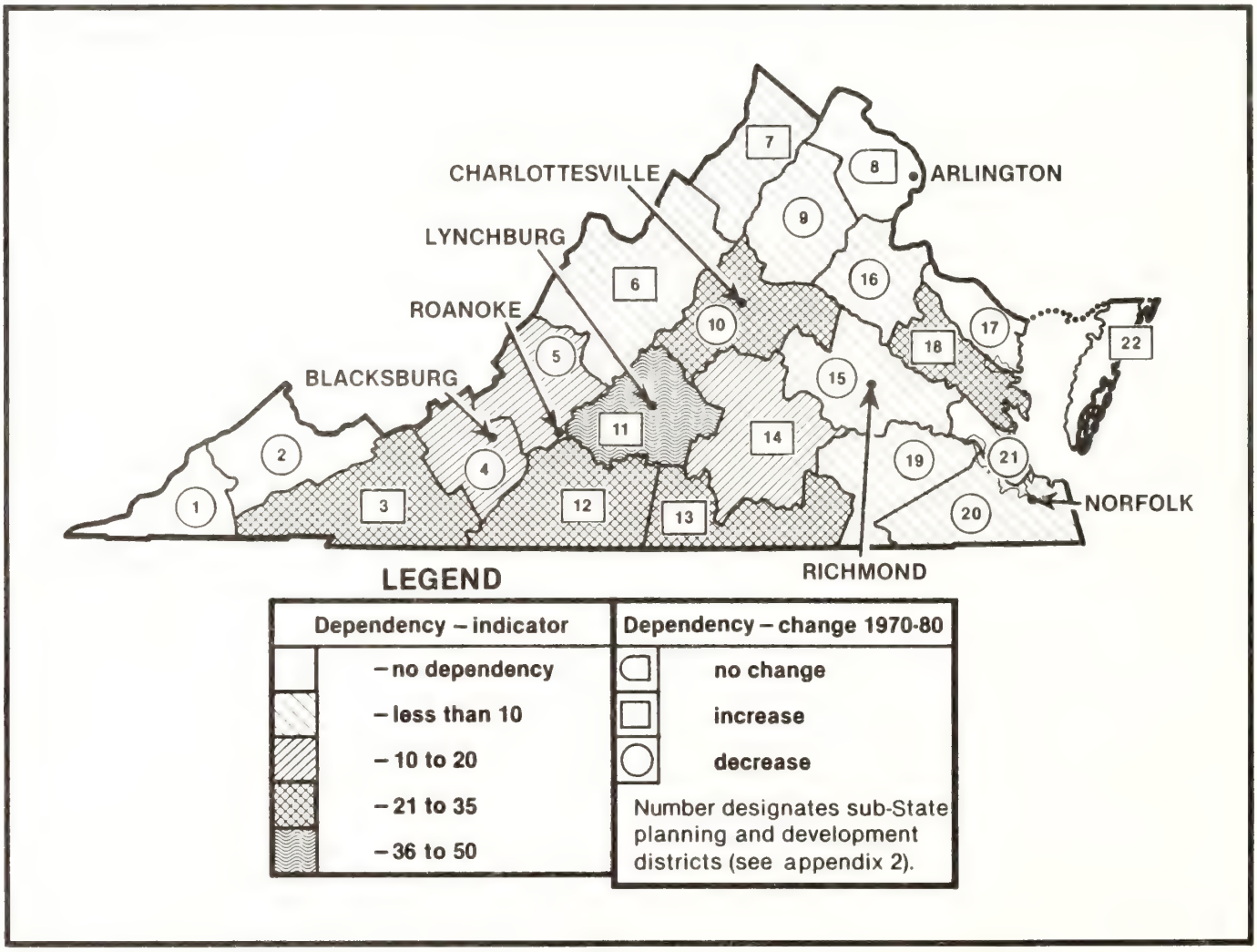
One interesting change involved the personal, miscellaneous business, and repair service industry, which did not qualify as a basic industry in 1970 but did by 1980. This change reflected the growing importance of electronic data processing and consulting services in the vicinity of Washington, DC.

Economic base industries	Employment		Earnings	
	1970	1980	1970	1980
	(Percent of economic base)			
Federal military	35.71	34.04	30.43	27.73
Federal civilian	26.12	26.78	38.05	35.27
Textiles and apparel	8.31	8.20	5.06	5.43
Construction	4.96	7.49	2.01	2.46
Forest products	6.26	6.29	4.28	3.71
Tobacco	4.10	4.69	4.18	6.62
Agriculture	4.91	3.82	[2/]	[2/]
Coal mining	2.67	3.28	4.27	6.65
Chemical and allied products	5.37	1.30	6.24	1.80
Personal, miscellaneous business, and repair service	0	3.13	0	4.51
Subtotal	98.41	99.02	94.52	94.18
All other industries	1.59	.98	5.48	5.82
Total	100.00	100.00	100.00	100.00

[2/]Less than 0.01 percent.

Geographical Importance of the State's Forest Products Industry

The contribution of the forest products industry to Virginia's economic base varies considerably between sub-State districts (see appendix 2 for a listing of counties by district). Generally speaking, the forest products industry is more important in south-central Virginia than elsewhere. For example, the forest products industry accounts for more than 35 percent of the economic base employment in the Lynchburg area but for less than 10 percent in the Richmond area. Between 1970 and 1980, dependency on the forest products industry increased in most of the State's more heavily dependent sub-State districts and declined elsewhere.

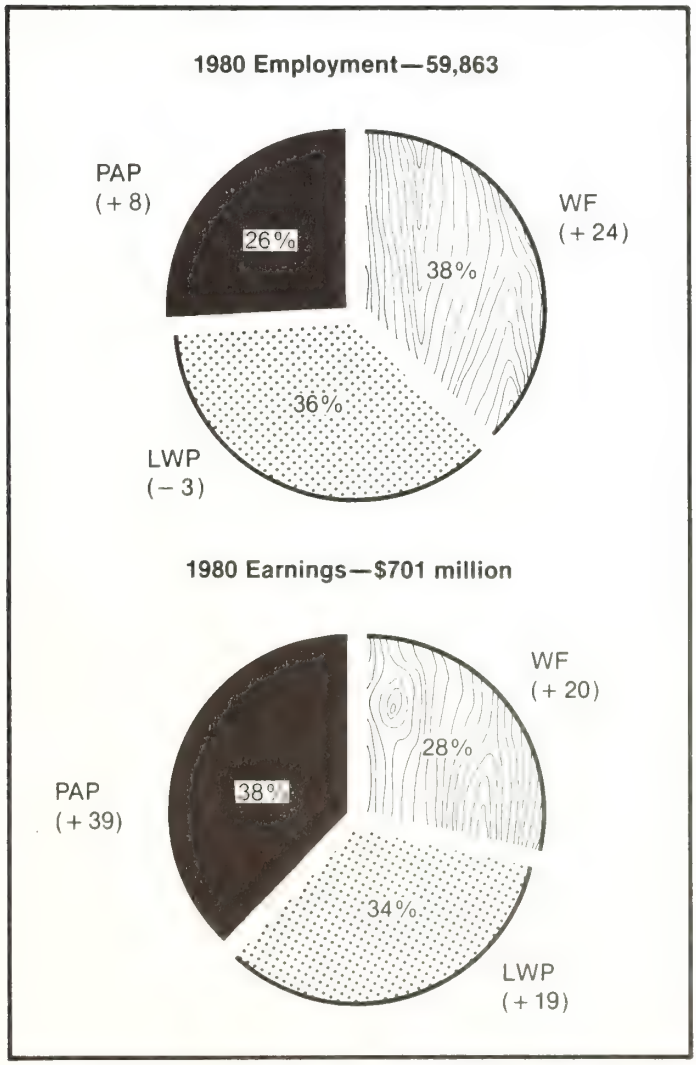


Source: Sub-State estimates for 1970 and 1980 were derived from unpublished county data series provided by the U.S. Department of Commerce, Regional Economic Information System, Washington, DC; and from the Department's *County Business Patterns*. The numbers designate sub-State districts corresponding to the geographical classification of counties as shown in appendix 2.

Composition of the State's Forest Products Industry

Virginia's forest products industry is comprised of paper and allied products, lumber and wood products, and wood furniture manufacturing. In 1980, wood furniture accounted for the largest share of approximately 60,000 workers employed by Virginia's forest products industry. Paper and allied products had the largest share of earnings in 1980.

During the 1970's, employment in the wood furniture component increased at a substantially faster rate than it did for paper and allied products, while employment dropped in the lumber and wood products component of the industry. The growth rate for wood furniture was nearly the same as the average for all industries in the Nation (22.3 percent). Earnings of paper and allied products increased at a substantially faster rate than for all industries (27.7 percent).

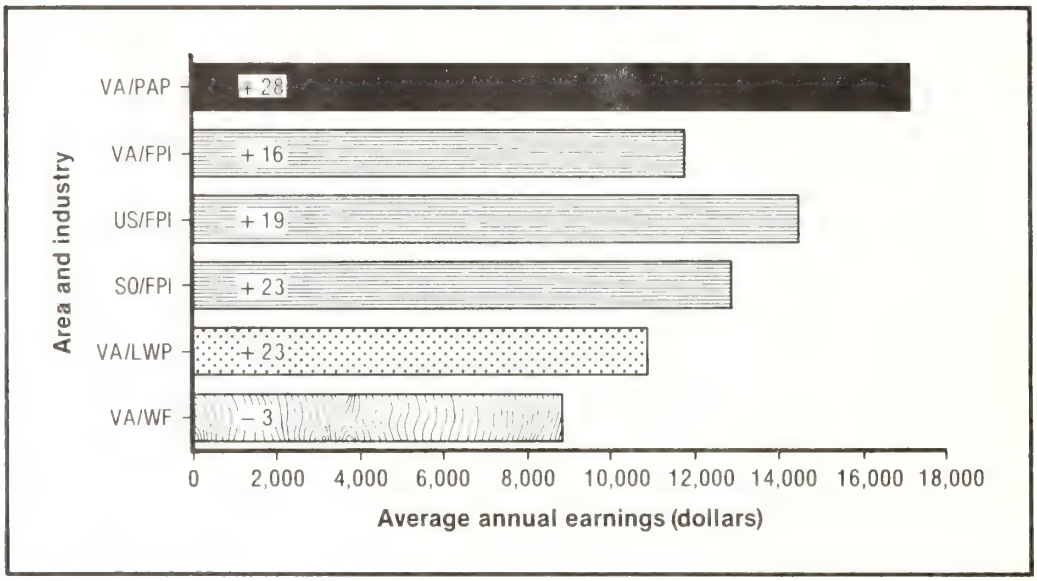


Numbers in parentheses show percentage of change from 1970 to 1980.

Average Annual Earnings per Worker

Average annual 1980 earnings per worker in paper and allied products were significantly greater than were earnings in the other two components of Virginia's forest products industry. Higher average skill levels, capital investment per worker, and unions account for this difference. Earnings in the wood furniture component were approximately 50 percent of those for paper and allied products and were significantly below the average for all forest products industries in the South and the United States.

The rate of growth in earnings was less for Virginia's forest products industry than for the South and the Nation. The difference resulted from the decrease in average earnings of the wood furniture segment. The rate of growth for lumber and wood products and for paper and allied products was equal to or greater than that for the United States and the South.

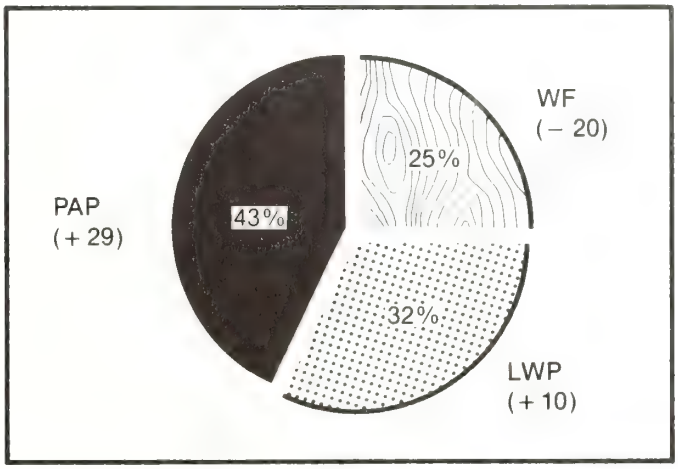


Numbers in bars show percentage of change from 1970 to 1980

Value Added by the Forest Products Industry

Value added by manufacturing represents income payments made directly to workers and business owners. It is equal to the value of shipments less the cost of materials, parts, supplies, fuel, goods purchased for resale, electric energy, and contract work. Unlike value of shipments, value added includes only the economic contributions of the State's forest products industry. Consequently, value added by manufacturing is considered a better monetary gauge of the relative economic importance of a manufacturing industry.

In 1977, paper and allied products accounted for the largest share of the $1.27 billion of value added by Virginia's forest products industry. Between 1972 and 1977, the value added by paper and allied products and by lumber and wood products increased, but value added decreased for wood furniture.

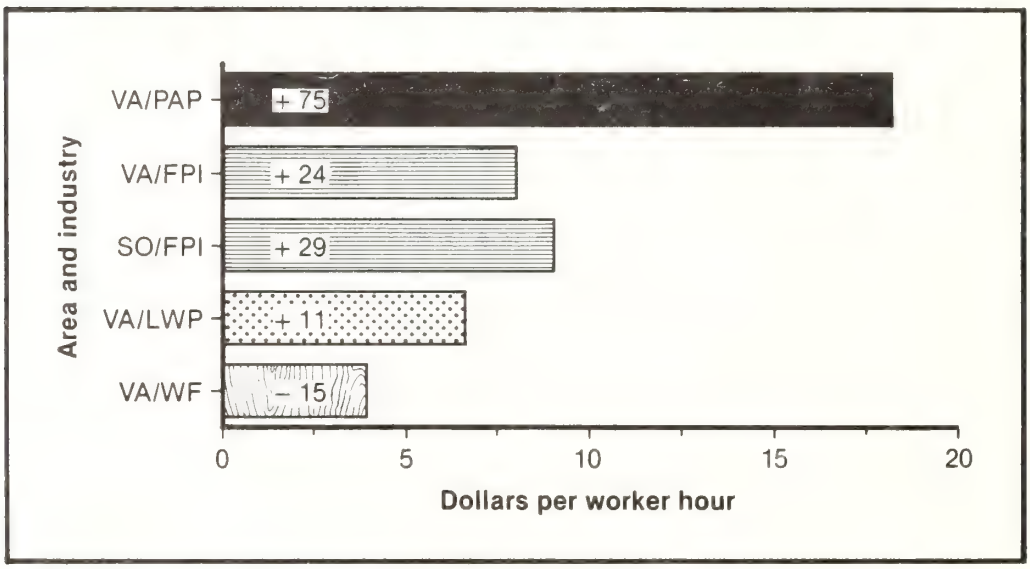


Numbers in parentheses show percentage of change from 1972 to 1977.

Capital Productivity

Increases in productivity are necessary for an industry to remain competitive in the marketplace. Capital productivity of an industry is measured in terms of value added minus payrolls per worker hour (see table 3 for an explanation of how productivity was calculated for Virginia's forest products industry). This measure of productivity adjusts for wide differences in payroll among industries and represents profits before taxes.

In 1977, the productivity of paper and allied products was much higher than was productivity of the other two segments of Virginia's forest products industry. This is generally the case throughout the South and results from paper and allied products being more capital intensive than the other two segments and having attracted considerable investment funds for new facilities and equipment.

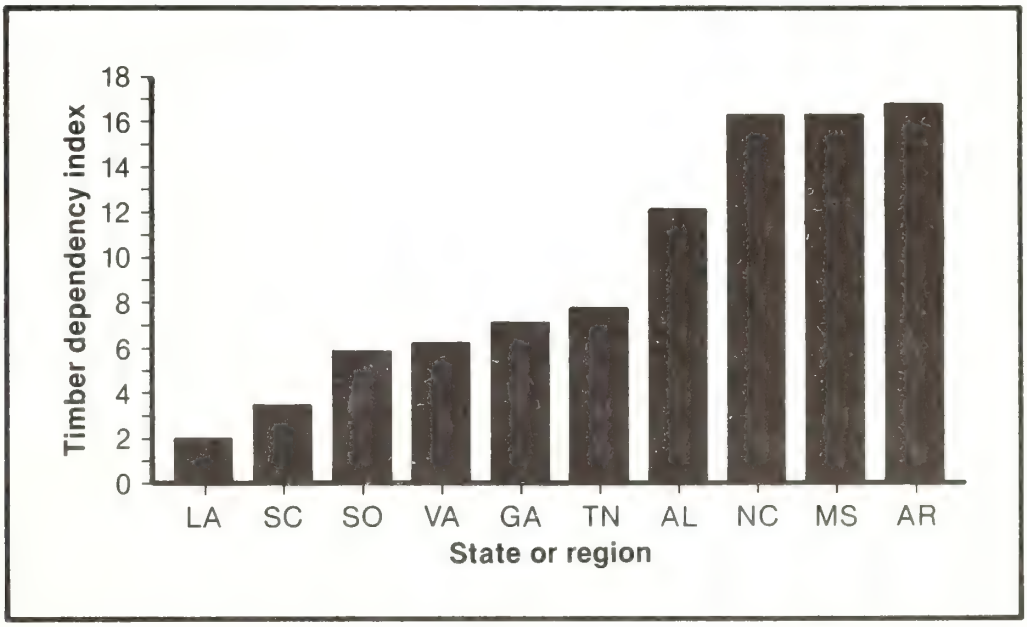


Numbers in bars show percentage of change from 1972 to 1977.

The Forest Products Industry in the South

Importance of the Industry Across the South

The dependency indicators suggest that in 1980 all but four States in the South manufactured forest products in excess of statewide needs. Florida, Kentucky, Oklahoma, and Texas were not self-sufficient with respect to forest products. That is, these States imported more forest products than they exported. Consequently, on net balance, their respective forest products industries did not generate new dollars from the outside. In three States—Arkansas, Mississippi, and North Carolina—the forest products industry accounts for approximately one out of six basic employees.



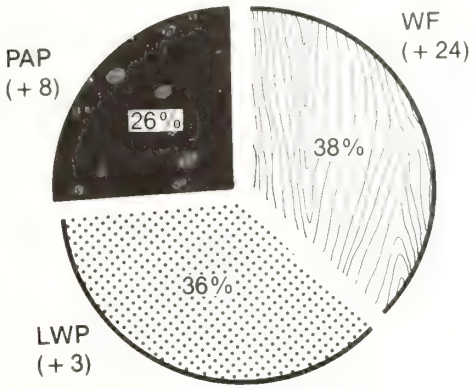
Industry Composition

Wood furniture accounted for a much larger share of Virginia's forest products industry employment in 1980 than it did for either the South or the Nation. Furthermore, the rate of growth in Virginia exceeded that for the South and the Nation.

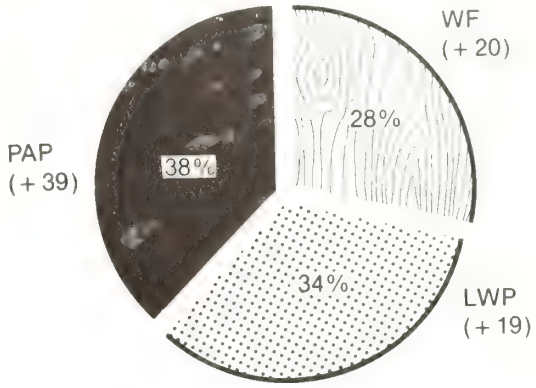
In terms of earnings, Virginia's forest products industry was more evenly divided among the three segments than was the case for the South and the Nation. Growth in earnings for Virginia's forest products industry (26 percent) was less than for the South (36 percent) but greater than for the Nation (23 percent).

VIRGINIA

1980 Employment—59,863

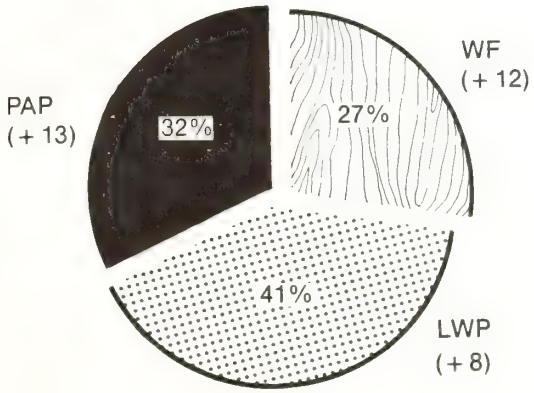


1980 Earnings—$701 million

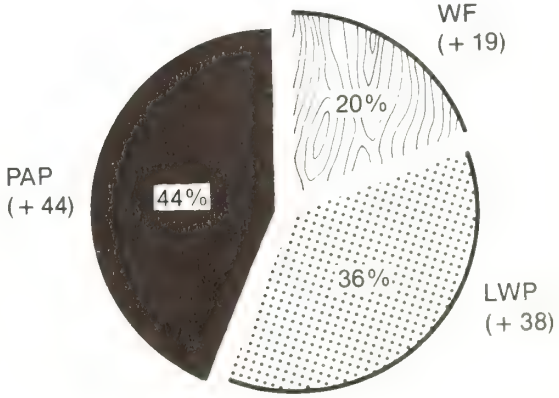


THE SOUTH

1980 Employment—620,567

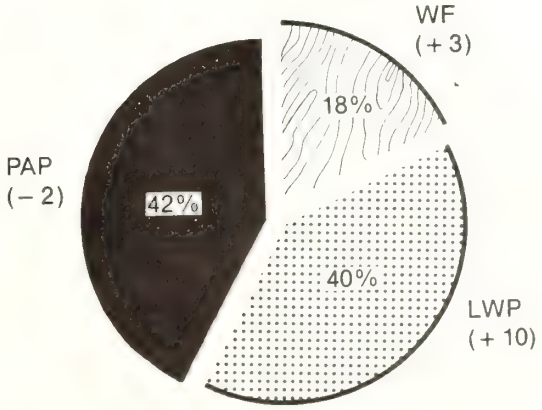


1980 Earnings—$7.96 billion

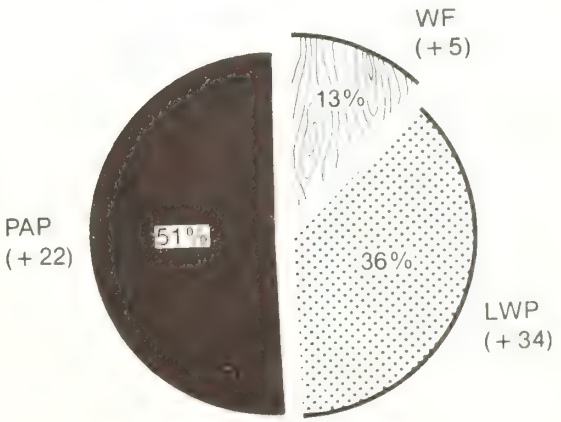


UNITED STATES

1980 Employment—1,634,000



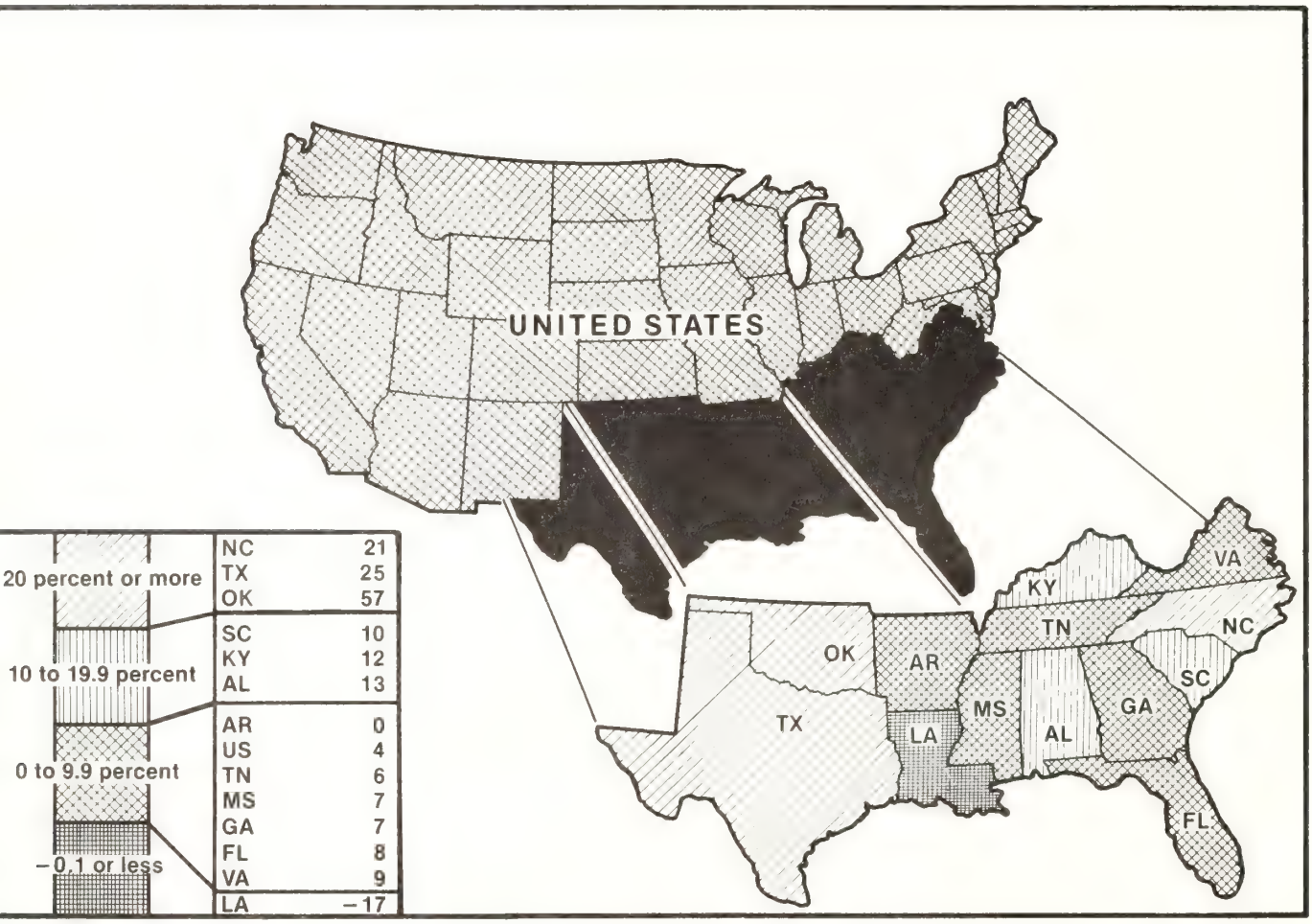
1980 Earnings—$23.65 billion



Numbers in parentheses show percentage of change from 1970 to 1980.

Growth of Employment

With the exceptions of Arkansas and Louisiana, forest products industry employment in each of the Southern States grew faster from 1970 to 1980 than did the U.S. counterpart. Employment in two States—Oklahoma and Texas—grew faster than the all-industry average of 22.3 percent. Growth in employment for Virginia's forest products industry was more than twice the industry's national rate.

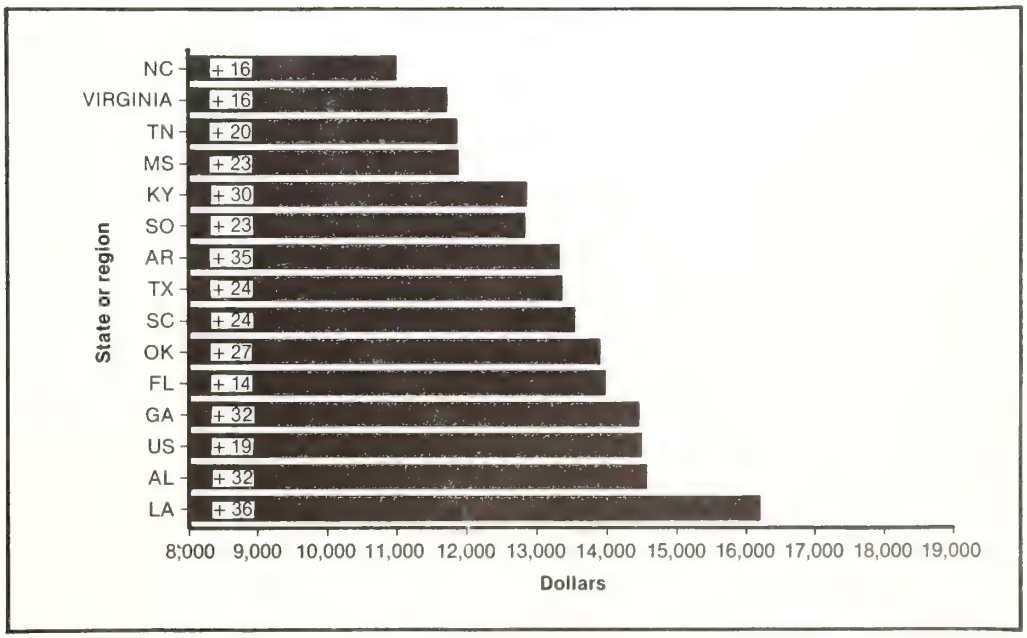


Average Annual Earnings

Average annual earnings per worker in the forest products industry differed significantly by State in 1980; approximately $5,000 separated the State with the highest (Louisiana) from the State with the lowest (North Carolina). Pulp and allied products manufacturing, which has traditionally paid higher wages than have other components of the forest products industry, dominated Louisiana's forest products industry. Wood furniture, which has paid lower average wages, dominated North Carolina's industry.

Average annual earnings per worker in Virginia's forest products industry were less than earnings for either the South or the United States. In addition, earnings increased at a slower pace in Virginia than in either the South or the Nation. Virginia ranked 12th among the 13 Southern States both in terms of the average earnings in 1980 and the rate of change between 1970 and 1980.

Generally speaking, paper and allied products employment dominated the forest products industry in the States with the highest average annual earnings. This relationship reflects higher job skills and unions in the paper industry. Wages, by and large, were the lowest in States where the labor-intensive wood furniture industry was of greater importance.



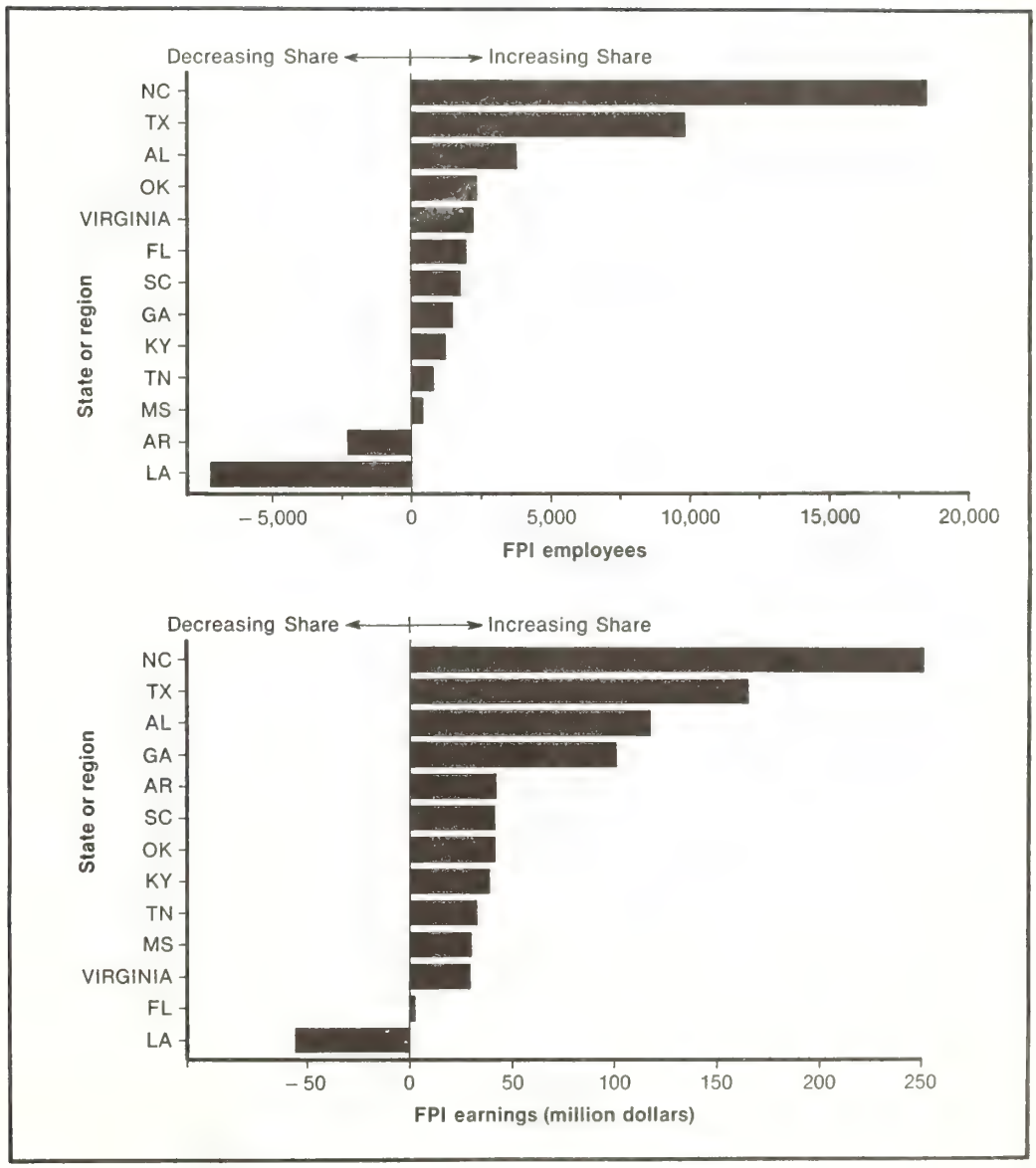
Numbers in bars show percentage of change from 1970 to 1980.

Shift in Employment and Earnings

The regional shift shows how much more or less employment and earnings a State would have had in the forest products industry in 1980 had it grown at the national rate. For example, Virginia had approximately 2,300 more employees in 1980 than it would have had if its forest products industry had grown at the national rate.

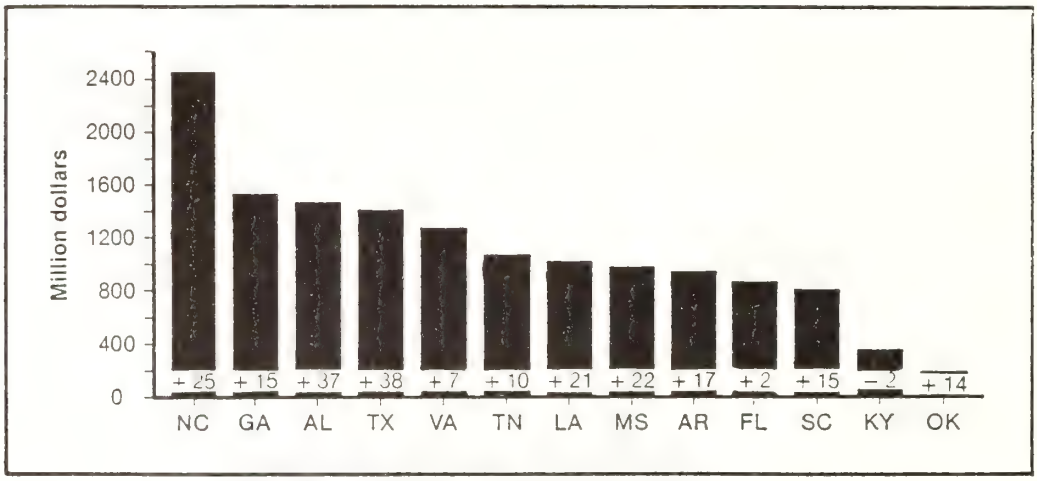
Between 1970 and 1980, employment in the forest products industry increased in every Southern State except Louisiana and Arkansas; moreover, all but these two States increased their share of the Nation's forest products industry employment, and all but Louisiana increased their share of earnings. Virginia's increase in the share of the Nation's employment in the forest products industry was 5th among the 13 Southern States; its increase in the share of earnings was 11th.

Increased shares of employment and earnings reflect the comparative advantage the South's forest products industry enjoyed over this industry in the rest of the Nation. Several factors (for example, relatively lower labor costs, lower raw materials costs, and closer proximity to markets) might account for a region's comparative advantage, although adverse trends with respect to one factor need not reduce a region's advantage. In the South, for instance, increasing labor costs need not adversely affect the comparative advantage if increased capital or labor productivity offsets higher labor costs.


Decreasing Share
Increasing Share
NC
TX
AL
OK
VIRGINIA
FL
SC
GA
KY
TN
MS
AR
LA
State or region
– 5,000
0
5,000
10,000
15,000
20,000
FPI employees
Decreasing Share
Increasing Share
NC
TX
AL
GA
AR
SC
OK
KY
TN
MS
VIRGINIA
FL
LA
State or region
– 50
0
50
100
150
200
250
FPI earnings (million dollars)

Value Added by the Forest Products Industry

In 1977, the forest products industry of North Carolina produced more value added than any other State in the South. Georgia was second among the 13 Southern States, followed by Alabama. Texas was not only one of the leading States in terms of total value added but also led the South in terms of the change in value added between 1972 and 1977. Virginia was fifth in terms of total value added. Between 1972 and 1977, the increase in total value added by Virginia's forest products industry ranked 11th among the 13 Southern States. One State, Kentucky, produced less value added in 1977 than in 1972.

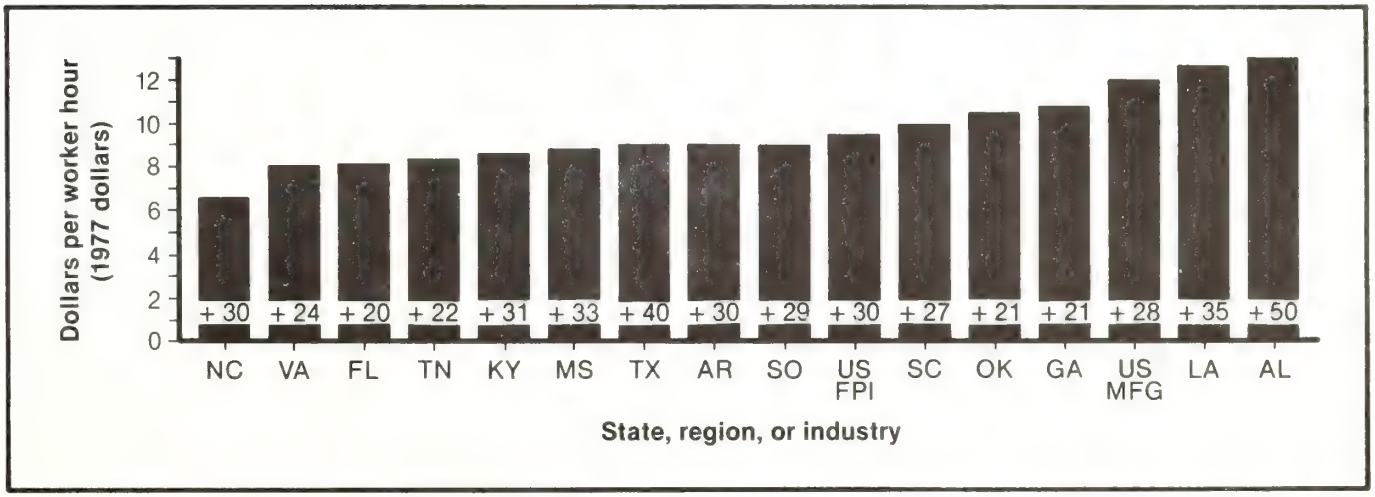


Numbers in bars show percentage of change from 1972 to 1977.

Capital Productivity

Paper and allied products industry, which is more capital-intensive and therefore more susceptible to technological change than are other segments of the forest products industry, exhibited the highest productivity within the forest products industry. Wood furniture, on the other hand, is the most labor-intensive of the three segments. North Carolina, for example, produced more value added than any other State in the South, but the productivity of its forest products industry in 1977 was the lowest. In 1977, capital productivity of the forest products industries of North Carolina and Virginia were the lowest of the Southern States, reflecting the dominant role of the labor-intensive furniture industry.

Increases in productivity exceeded increases in payroll per worker between 1972 and 1977 for all the Southern States. This relationship is in part responsible for the South's comparative advantage in the forest products industry. The change in productivity between 1972 and 1977 was also below the regional and national levels.



Numbers in bars show percentage of change from 1972 to 1977.

Acknowledgment

Many helpful suggestions of several reviewers were incorporated in this research paper. This project was partially funded by the USDA Forest Service, Resource Program and Assessment Staff, State and Private Forestry, Area Planning and Development, State Planning for Forest Resources.

Appendix 1
Tables

Table 1—Total labor and proprietorial employment and income, by industry, Virginia, 1980 [1/]

Industry number	Industry	Employees	Total income
		Number	*Thousand 1977 dollars* [2/]
Wage and salary			
1	Agriculture	26,299	216,983
2	Agricultural services, forestry, and fisheries	8,933	93,381
3	Coal mining	19,107	468,464
4	Oil and gas extraction	152	3,834
5	Metal mining	342	4,177
6	Nonmetallic minerals	2,888	38,446
7	Construction	131,505	1,706,610
8	Food and kindred products	41,697	448,476
9	Tobacco	17,596	361,902
10	Textile mill production	45,984	453,932
11	Apparel and other textiles	333,675	235,787
12	Paper and allied products	15,449	264,472
13	Printing and publishing	22,339	270,835
14	Chemical and allied products	31,658	563,389
15	Petroleum refining	305	8,230
16	Rubber and miscellaneous plastics	11,589	171,426
17	Leather and leather products	3,595	25,823
18	Lumber and wood products, excluding mobile homes	21,852	237,276
19	Mobile homes	707	7,677
20	Wood furniture	22,562	199,496
21	Other furniture and fixtures	3,204	28,330
22	Stone, clay, and glass products	12,867	170,670
23	Primary metals	12,826	232,012
24	Fabricated metals	22,773	356,560
25	Machinery, excluding electrical	15,272	220,417
26	Electrical machinery	34,257	528,332
27	Transportation equipment, excluding motor vehicles	31,525	498,468
28	Motor vehicles	7,542	124,624
29	Ordnance	[3/]	[3/]
30	Instruments and related equipment	4,281	49,853
31	Miscellaneous manufacturing	2,806	29,846
32	Railroad transportation	14,522	276,227
33	Trucking and warehousing	28,232	411,873
34	Local transit	5,901	66,271
35	Air transportation	12,136	287,445

See footnotes at end of table.

Table 1—Total labor and proprietorial employment and income, by industry, Virginia, 1980 [1/] (continued)

Industry number	Industry	Employees	Total income
		Number	*Thousand 1977 dollars [2/]*
Wage and salary			
36	Pipeline transportation	119	2,806
37	Transportation services	2,967	38,348
38	Water transportation	4,907	69,074
39	Communications	30,681	569,679
40	Electrical, gas, and sanitation services	16,292	282,494
41	Wholesale trade	105,406	1,544,120
42	Retail trade	347,495	2,602,760
43	Banking	33,634	346,694
44	Other credit agencies	18,078	235,613
45	Insurance	29,152	422,233
46	Real estate and combinations	29,942	375,888
47	Hotel and other lodging	30,496	202,336
48	Personal, miscellaneous business, and repair services	115,583	1,326,027
49	Auto repair service	12,232	144,981
50	Amusement	14,354	90,097
51	Motion pictures	2,933	15,644
52	Private households	54,552	155,131
53	Medical and other health	105,865	1,384,659
54	Private education	25,460	180,978
55	Nonprofit organizations	60,112	467,216
56	Miscellaneous services	36,489	767,967
57	Federal civilian	164,103	2,810,280
58	Federal military	175,557	1,798,029
59	State and local government	335,678	3,009,156
Proprietorial			
60	Farm proprietors	66,203	131,669
61	Nonfarm proprietors	141,646	1,460,254
	Total	2,626,405	29,495,707

[1/]Source of data for this table for Virginia, other States of the South, and the United States: unpublished data, U.S. Department of Commerce, Regional Economics Measurements Division, Regional Economic Information System (REIS), Washington, DC, 1982. Unpublished data used by the U.S. Department of Commerce in preparing their *County Business Patterns* (CBP) series on employment and payroll were used to differentiate wood-related from nonwood-related employment and earnings. For example, CBP data were used to separate mobile homes (no. 19) from the lumber and wood products (no. 18) industry. Wood furniture (no. 20) was similarly separated from other furniture and fixtures (no. 21).

[2/]The Personal Consumption Expenditures (PCE) deflator, 1977 = 100, was used to deflate actual dollars.

[3/]Included with fabricated metals and other related industries.

Table 2—Calculation of 1980 dependency indexes for Virginia [1/]

(In percent)

Industry	Employment		Virginia excess employment [2/]	Dependency index [3/]
	Virginia	United States		
Agriculture	1.18	1.46	—	—
Agricultual services, forestry, and fisheries	.40	.62	—	—
Farm proprietors	2.96	3.03	—	—
Coal mining	.85	.27	0.58	3.82
Oil and gas extraction	.01	.60	—	—
Metal mining	.02	.11	—	—
Nonmetallic minerals	.13	.14	—	—
Construction	5.88	4.74	1.14	7.49
Food and kindred products	1.86	1.87	—	—
Tobacco	.79	.07	.71	4.69
Textile mill production	2.06	.93	1.13	7.41
Apparel and other textiles	1.51	1.39	.12	.79
Paper and allied products	.69	.76	—	—
Printing and publishing	1.00	1.37	—	—
Chemical and allied products	1.42	1.22	.20	1.30
Petroleum refining	.01	.22	—	—
Rubber and miscellaneous plastics	.52	.80	—	—
Leather and leather products	.16	.26	—	—
Lumber and wood products, excluding mobile homes	.98	.71	.27	1.77
Mobile homes	.03	.05	—	—
Wood furniture	1.01	.32	.69	4.52
Other furniture and fixtures	.14	.19	—	—
Stone, clay, and glass products	.58	.73	—	—
Primary metals	.57	1.26	—	—
Fabricated metals	1.02	1.77	—	—
Machinery, excluding electrical	.68	2.73	—	—
Electrical machinery	1.53	2.31	—	—
Transportation equipment, excluding motor vehicles	1.41	1.21	.20	1.30
Motor vehicles	.34	.87	—	—
Instruments and related equipment	.19	.77	—	—
Miscellaneous manufacturing	.13	.47	—	—
Railroad transportation	.65	.58	.07	.43
Trucking and warehousing	1.26	1.40	—	—
Local transit	.26	.29	—	—
Air transportation	.54	.50	.04	.29
Pipeline transportation	.01	.02	—	—
Transportation services	.13	.22	—	—
Water transportation	.22	.23	—	—
Communications	1.37	1.48	—	—
Electrical, gas, and sanitation services	.73	.90	—	—
Wholesale trade	4.71	5.79	—	—
Retail trade	15.54	16.50	—	—
Banking	1.50	1.72	—	—
Other credit agencies	.81	.99	—	—

See footnotes at end of table.

Table 2—Calculation of 1980 dependency indexes for Virginia [1/] (continued)
(In percent)

Industry	Employment		Virginia excess employment [2/]	Dependency index [3/]
	Virginia	United States		
Insurance	1.30	1.89	—	—
Real estate and combinations	1.34	1.16	.18	1.18
Hotel and other lodging	1.36	1.20	.16	1.08
Personal, miscellaneous business, and repair services	5.17	4.69	.48	3.13
Auto repair service	.55	.63	—	—
Amusement	.64	.84	—	—
Motion pictures	.13	.24	—	—
Medical and other health	4.73	5.71	—	—
Private education	1.14	1.47	—	—
Nonprofit organizations	2.69	3.01	—	—
Miscellaneous services	1.63	1.63	—	—
Federal civilian	7.34	3.27	4.08	26.78
Federal military	7.85	2.68	5.17	34.04
Nonfarm proprietors	6.33	7.66	—	—
Total [3/]	100.00	100.00	15.19	100.00

[1/]Virginia employment minus U.S. employment. Figures may not be exactly equal to U.S. minus Virginia because of rounding. Dashes signify no excess employment.

[2/]Individual industry excess employment expressed as a percentage of Virginia's total excess employment (sum of column 4).

[3/]Sum of parts may not equal totals because of rounding.

Table 3—Value added, hours worked, payroll, and capital productivity, [1/] Virginia forest products industry, 1977 [2/]

Industry	Value added	Payroll	Hours worked	Productivity	Productivity change, 1972-77
	- - - - *$Million* - - -		*Million*	*$VAMP per hour*	*Percent*
Lumber and wood products	405.7	182.3	33.8	6.61	11.41
Wood furniture	315.4	164.6	38.2	3.95	-15.42
Paper and allied products	546.2	187.7	19.7	18.20	75.02

[1/]Productivity equals value added minus payroll (VAMP) divided by hours worked. For a discussion of VAMP, see W. Charles Sawyer and Joseph A. Ziegler, 1980. "The use of VAMP shift as a predictive model." Unpublished paper presented at the annual meeting of the Western Regional Science Association, Monterey, California.

[2/]Source: U.S. Bureau of the Census, Census of Manufactures, for 1972 and 1977, Virginia and the United States, available in 1976 and 1980, respectively. In the few instances where data were not available for some segments of the forest products industry, the distribution of the number of establishments was used to estimate nondisclosures.

Appendix 2
Virginia Counties by Sub-State Planning and Development Districts

District code	Counties
1	Lee, Scott, Wise
2	Buchanan, Dickenson, Russell, Tazewell
3	Bland, Carroll, Grayson, Smyth, Washington, Wythe
4	Floyd, Giles, Montgomery, Pulaski
5	Alleghany, Botetourt, Craig, Roanoke
6	Augusta, Bath, Highland, Rockbridge, Rockingham
7	Clarke, Frederick, Page, Shenandoah, Warren
8	Arlington, Fairfax, Loudoun, Prince William
9	Culpeper, Fauquier, Madison, Orange, Rappahannock
10	Albemarle, Fluvanna, Greene, Louisa, Nelson
11	Amherst, Appomattox, Bedford, Campbell
12	Franklin, Henry, Patrick, Pittsylvania
13	Brunswick, Halifax, Mecklenburg
14	Amelia, Buckingham, Charlotte, Cumberland, Lunenburg, Nottoway, Prince Edward
15	Charles City, Chesterfield, Goochland, Hanover, Henrico, New Kent, Powhatan
16	Caroline, King George, Spotsylvania, Stafford
17	Lancaster, Northumberland, Richmond, Westmoreland
18	Essex, Gloucester, King and Queen, King William, Mathews, Middlesex
19	Dinwiddie, Greensville, Prince George, Surry, Sussex
20	Isle of Wight, Nansemond, Southampton
21	James City, York
22	Accomack, Northampton

Schallau, Con H; Maki, Wilbur R.; Foster, Bennett B.; Redmond, Clair H. Virgina's forest products industry: performance and contribution to the State's economy, 1970 to 1980. Res. Pap. PNW-368. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

Employment and earnings in Virginia's forest products industry, like those of most Southern States, increased between 1970 and 1980. Furthermore, Virginia's share of the Nation's forest products employment and earnings increased during this period. In 1980, the wood furniture segment accounted for the largest share of the industry's employment, but paper and allied products accounted for the largest share of earnings. In 1977, pulp and allied products had higher productivity than either lumber and wood products or wood furniture.

Keywords: Forest products industries, economics (forest products industries), employment (forest products industries), Virginia.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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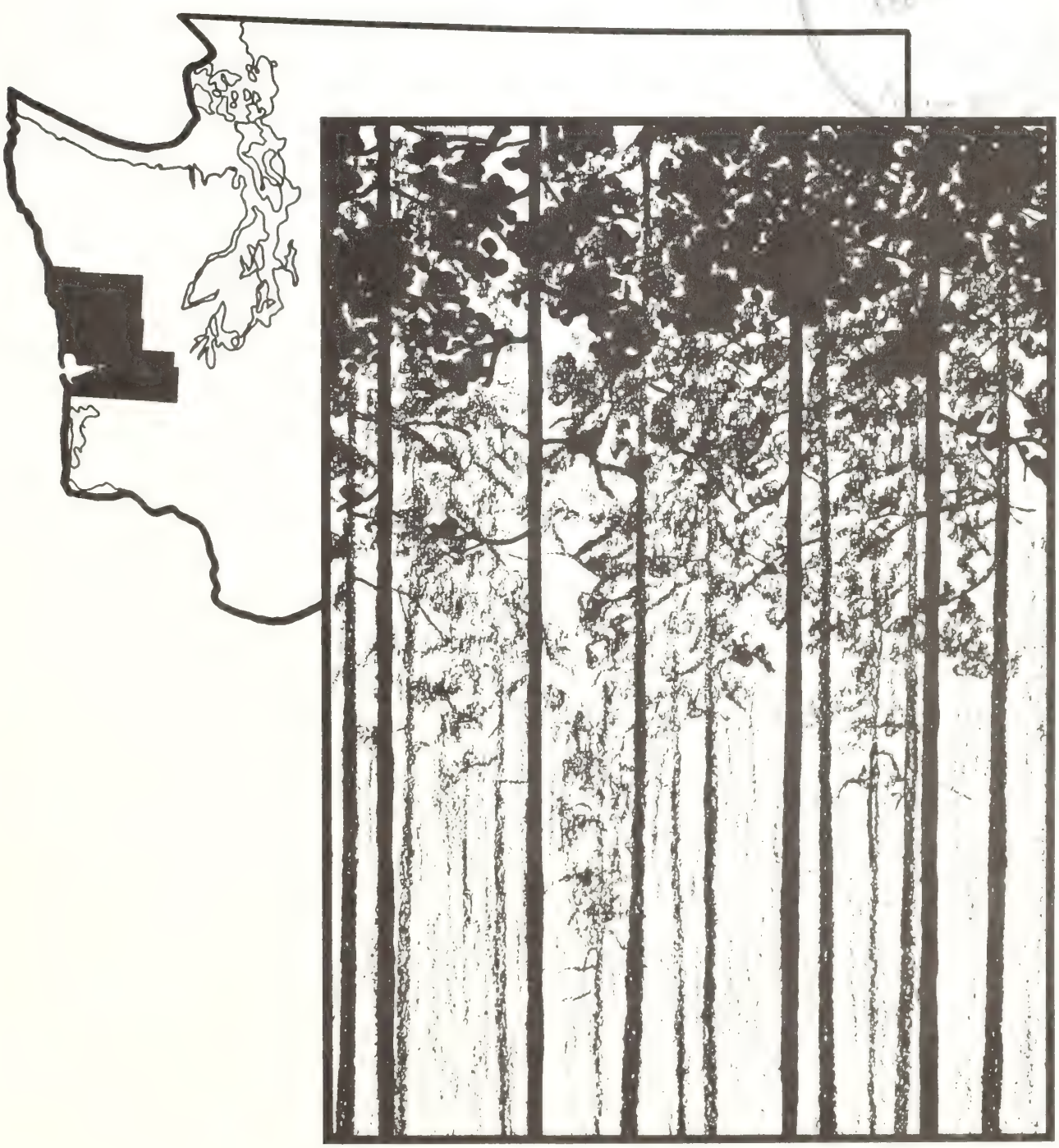
PNW-369

October 1986

Are Federal Sustained Yield Units Equitable? A Case Study of the Grays Harbor Unit

Con H Schallau and Wilbur R. Maki



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Abstract

Schallau, Con H; Maki, Wilbur R. Are Federal sustained yield units equitable? A case study of the Grays Harbor unit. Res. Pap. PNW-369. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 17 p.

The Grays Harbor Federal Sustained Yield Unit (U.S. Department of Agriculture, Forest Service) was established in 1949 to enhance the economic stability of the forest products industry and dependent communities in Grays Harbor County, Washington. Provisions of the unit's charter require that all logs harvested from the Quinault Ranger District of the Olympic National Forest receive primary processing in Grays Harbor County. Periodic reviews have resulted in few changes in the operation of the unit. In 1981, however, restrictions were incrementally relaxed so that by 1985, only 50 percent of the logs had to be processed in Grays Harbor County. This paper describes an analysis that was part of a review to determine whether the 1981 change should be continued or rescinded. Findings of this study suggest that the forest products industry and the economy in Grays Harbor County are healthier than in the contiguous nonmetropolitan counties and that continuing the restriction may be to the detriment of neighboring counties that are not as well off.

Keywords: Sustained yield, economic impact, economics (forest products industries), community stability.

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3 The Total Work Force

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Introduction

The 1944 Federal Sustained Yield Forest Management Act of March 20, 1944 (58 Stat. 132; 16 U.S.C. 583, 583a-583i), authorizes the Secretaries of Agriculture and the Interior to establish sustained yield units consisting of forest land under their respective jurisdictions. These units could be established (sec. 3):

> whenever...the maintenance of a stable community or communities is primarily dependent upon the sale of timber or other forest products from federally owned or administered forest land and such maintenance cannot effectively be secured by following the usual procedure in selling such timber or other forest products....

In 1949, pursuant to this act, the Secretary of Agriculture authorized the creation of the Grays Harbor Federal Sustained Yield Unit. [1/] With the creation of this unit, primary processing of logs harvested from the Quinault Ranger District of the Olympic National Forest was restricted to Grays Harbor County, Washington (fig. 1). Since the inception of the unit, however, this restriction has been waived for some log buyers so they can market timber outside the zone of primary manufacture.

The importance of the timber harvested from the unit has varied considerably. In 1949, the unit accounted for 33 percent of the logs consumed in Grays Harbor County; in 1976 it accounted for only 6 percent. From 1981 to 1984, the unit's contribution ranged from 8 to 15 percent.[2/]

Policy reviews of the unit were conducted in 1954, 1958, 1960, 1967, and 1978. Except for a change suggested in the 1967 review—to include chips in the definition of primary processing—the management policy did not change appreciably until 1981. At that time, primary processing restrictions were relaxed incrementally so that by 1985 only 50 percent of the logs harvested from the unit had to be processed in Grays Harbor County.

The primary processing requirement was relaxed to determine if the location of primary processing of timber harvested within the unit would change. In effect, relaxing the requirement increased the availability of raw material to the forest products industry outside the unit. Furthermore, increased competition might result in higher bid prices. Since 1981, however, the major problem facing the forest products industry throughout the Pacific Northwest has been limited markets. So, despite the relaxing of the primary processing requirements, increased competition for the unit's timber has not materialized. Nevertheless, some timber harvested from the unit continued to be sent to processing facilities outside Grays Harbor County (see appendix table 6).

[1/] Two sustained yield units are in the State of Washington. In 1946, the Shelton Cooperative Sustained Yield Unit resulted from an agreement between the Forest Service and the Simpson Timber Company. This agreement, unlike the Grays Harbor Sustained Yield Unit, committed designated National Forest and Simpson Timber Company land in Grays Harbor, Mason, and Thurston Counties to cooperative management. This agreement terminates on December 31, 2046 (58 Stat.: 16 U.S.C. 583-5831, Suppl. 4).

[2/] See appendix table 5 and Leonard Guss Associates, Inc. (1980).

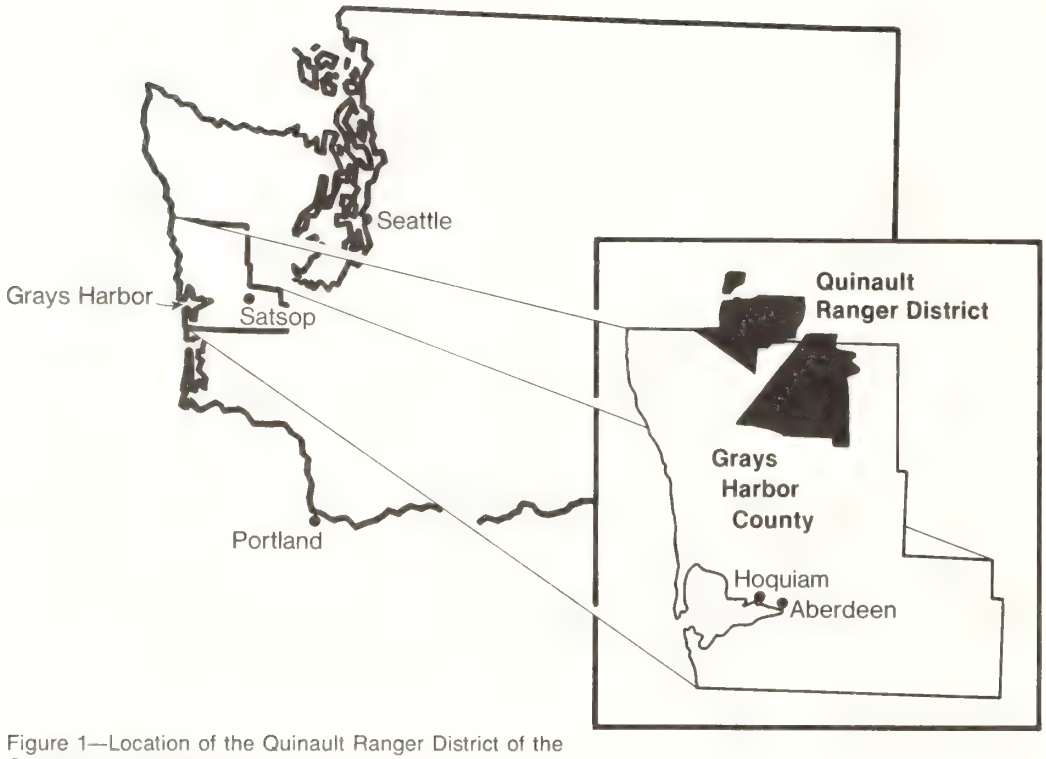

Figure 1—Location of the Quinault Ranger District of the Olympic National Forest.

It may be too early to evaluate all the ramifications of relaxing the unit's primary processing restrictions. The Nation's economy was growing rapidly during the 1970's. But since 1981, when the primary processing requirements were relaxed, it has experienced the most severe recession since World War II. The forest products industry of the Pacific Northwest has yet to fully recover from the severe economic stress caused by competition from sawmills and plywood mills in the South and by lumber imports from Canada. The economic turmoil of the 1975-85 period (that is, substantial growth followed by inflation and economic stagnation, followed by a very severe and protracted recession), however, provides a unique opportunity to contrast the economic performance of the forest products industry and dependent communities of Grays Harbor County with that in neighboring counties.

If Grays Harbor County needs preferential treatment, it should be most apparent in times of economic stress. Some economies are not able to accumulate sufficient wealth for a "rainy day" during the recovery and growth phases of a business cycle; such areas experience more trauma during a recession.

The original purpose of the Grays Harbor unit was to enhance the economy of the forest products industry and dependent communities of Grays Harbor County. The USDA Forest Service could well be meeting this objective. Given the contemporary situation, however, one could ask, "Is it fair that timber processors in Grays Harbor can bid on all National Forest timber sales—with the exception of the Shelton unit—while those in neighboring counties can't?" The process for resolving ques-

tions of fairness can be enhanced by having information about the economic vitality of the segments of the forest products industry and the dependent communities that stand to gain or lose as a result of the 1981 decision. The purpose of this analysis is to provide such information.

The Importance of the Forest Products Industry

The Total Work Force

The estimated full- and part-time work force in Grays Harbor County in 1983 was 28,216 employees and proprietors. Between 1975 and 1983, it increased faster than the national average (18.4 vs. 15.6 percent) but slower than the State of Washington average (24.2 percent). Manufacturing is the county's largest employer group (table 1). The forest products industry (that is, lumber and wood products and paper and allied products) accounts for most of the county's manufacturing employment—74 percent, compared with 20 percent for Washington and 7 percent for the Nation. "Personal, business, and professional services" is the largest employer in the State and the Nation.

Components of the Economic Base

Along with total employment there is another and perhaps more important way to judge an industry's contribution to the county's economy. For communities to grow and develop, they must attract new dollars from selling goods and services to the outside world. The industries that bring in new dollars by exporting products and services beyond local boundaries (that is, to buyers elsewhere in other States and nations) constitute an area's economic base.

Generally speaking, most manufacturing employment is classified as economic base (or "basic"), whereas service or "residentiary" employment (for example, barber shops, realty firms, schools, and local government) is primarily geared to producing for local needs. Some portion of the latter is also basic. For example, Federal military and civilian employment qualifies as a basic industry because taxpayers outside the county pay most of the cost.

Residentiary employment is supported by the economic base. Money flowing in provides income for wage earners and entrepreneurs to spend on locally purchased goods and services. Usually, the economic growth of a region depends on the success of its economic base.

We used the excess employment technique to identify the industries comprising the economic base of Grays Harbor County, the five contiguous nonmetropolitan counties (fig. 2), and the State of Washington. [3/] This technique is based on the assumption that the national distribution of employment and earnings among industries is the norm. Any industry with employment or earnings in excess of this norm is considered to be producing for markets outside the county (or sub-State district) and is part of Grays Harbor County's economic base. The percentage of excess employment serves as an indicator of the region's dependency on a particular industry for generating new dollars from outside the region. In 1983, three industries accounted for most of the economic base employment of Grays Harbor County (table 2).

[3/] For an explanation of various methods for bifurcating employment into the basic and residentiary sectors, see Bendavid (1974).

Table 1—The composition of the work force of Grays Harbor County, Washington, the State of Washington, and the United States, 1983 1/

Employer	Grays Harbor	Washington	United States
	Percent of total employment		
Manufacturing:			
Durable goods--			
Lumber and wood products	13.2	2.1	0.6
Other durable goods	3.2	7.9	9.0
Nondurable goods--			
Paper and allied products	3.0	.8	.6
Other nondurable goods	2.6	3.4	6.6
Total 2/	22.0	14.2	16.8
Personal, business, and professional services	17.9	18.3	19.8
Retail trade	14.1	15.0	14.6
State and local government	13.6	13.3	12.3
Contract construction	7.0	3.7	3.7
Transportation and communications	3.7	4.7	4.7
Finance, insurance, and real estate	2.2	4.9	5.3
Farm proprietors	2.0	2.2	2.5
Wholesale trade	1.9	5.0	5.0
Federal Government:			
Military	1.7	3.8	2.5
Civilian	1.0	3.4	2.8
Nonfarm proprietors	11.3	8.1	7.2
Agricultural services, forestry, and fisheries	.9	.9	.5
Agricultural production	.6	2.1	1.2
Mining	3/	.1	.9
Furniture	0	.2	.4
Total 2/	100.0	100.0	100.0

1/ Employment estimates for Grays Harbor County, other counties of the State of Washington, and the United States were derived from unpublished data, U.S. Department of Commerce, Regional Economics Measurements Division, Regional Economic Information System (REIS), Washington, DC. Estimates for 1983 were derived by using ratio estimators, based on unpublished 1983 data from the Washington Department of Economic Security's industry employment series for counties, to adjust the corresponding 1980 REIS employment series.

2/ Sum of parts may not equal total because of rounding.

3/ Less than 0.1 percent.

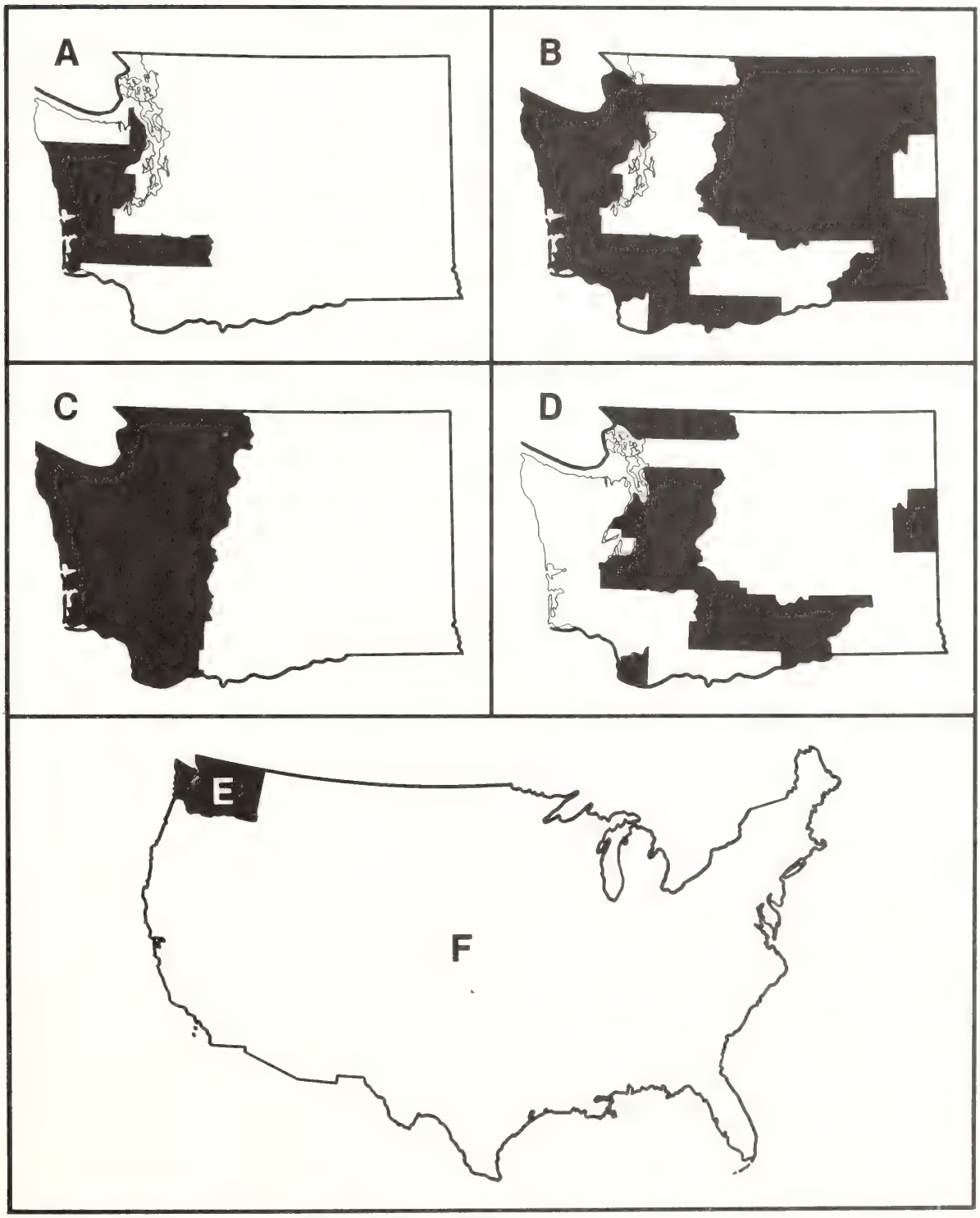

Figure 2—Reference areas: **(A)** five contiguous nonmetropolitan counties—Grays Harbor, Jefferson, Lewis, Mason, and Pacific; **(B)** nonmetropolitan Washington, including the five contiguous counties in "A"; **(C)** western Washington, including counties in "A"; **(D)** metropolitan Washington; **(E)** State of Washington; and **(F)** United States.

Table 2—Components of the economic base in the State of Washington and selected sub-State areas, 1975, 1980, and 1983

Economic base industry	Grays Harbor County			Contiguous nonmetropolitan counties 1/			State of Washington		
	1975	1980	1983	1975	1980	1983	1975	1980	1983
	Percent of economic base								
Forest products	79	60	62	64	57	53	27	25	22
Nonfarm proprietors	15	10	17	17	17	22	9	8	11
Contract construction	0	28	14	0	9	2	2/	9	2/
State and local government	6	1	5	10	10	13	21	11	14
Total	100	99	98	91	93	90	57	53	47
All other basic industries	0	1	2	9	7	10	43	47	53
Total	100	100	100	100	100	100	100	100	100

1/ Grays Harbor, Jefferson, Lewis, Mason, and Pacific Counties.

2/ Less than 1 percent.

Though these same industries accounted for about the same share in 1975, the change in shares of certain individual industries is noteworthy. Contract construction did not qualify as a basic industry in 1975, but it increased to 28 percent of total basic employment in 1980. This change reflected the beginning of construction of the nuclear reactor near Satsop, Washington.

Because of the relative increase in contract construction, the importance of the forest products industry decreased in Grays Harbor between 1975 and 1983. The data, however, are misleading. Employment data reflect place of work and not place of residence. Few of the employees of the forest products industry commuted from outside Grays Harbor, whereas many of the contract construction employees did. Furthermore, only a few caretaker employees are now working at the site of the mothballed nuclear plant. Consequently, the basic component of contract construction employment declined after 1983. Therefore, the forest products industry is as important now as it was before construction of the nuclear reactor was begun.

The decrease in importance of contract construction between 1980 and 1983 reflects the loss of more than 2,500 basic employees because the nuclear reactor was mothballed. Because many of the contract construction workers commuted to the reactor site (mainly from Thurston and Pierce Counties), the sharp drop in basic contract construction employment was not as traumatic for the Grays Harbor economy as the percentages suggest.

Most of the nonfarm proprietors are involved in activities related to forest products (for example, contract logging and hauling). For this reason, the importance of the forest products industry is slightly greater for the contiguous nonmetropolitan area than for Grays Harbor.

The Economic Vitality of Grays Harbor County

The establishment of the sustained yield unit granted preferential treatment to Grays Harbor County. This favoritism was rationalized because of the perceived need to assure stability for the county's forest products industry and dependent communities. The lack of an explicit definition of community stability in the Sustained Yield Forest Management Act complicates the recurring need to justify the existence of the unit. In this analysis we assume that preferential treatment might still be rationalized if the economic vitality of the timber industry and dependent communities of Grays Harbor County is surpassed by the economic vitality of nearby areas.

In this section we compare the economic vitality of Grays Harbor County with that of the Nation and selected areas in the State of Washington. We chose two indicators of economic vitality: (1) an area's comparative advantage and (2) industry profits before taxes.

The basic approach of the analysis of comparative advantage is to compare Grays Harbor County with the United States, Washington, and four subdivisions of the State: (1) five contiguous nonmetropolitan counties (Grays Harbor, Jefferson, Lewis, Mason, and Pacific); (2) nonmetropolitan Washington; (3) western Washington, and (4) metropolitan Washington. These four areas, the State of Washington, and the Nation are called reference areas (fig. 2; see appendix 2 for the listing of counties by reference area). These six reference areas are not mutually exclusive.

Change in Comparative Advantage

The change in regional shares of employment shows how much more or less employment Grays Harbor County would have had had its forest products industry grown at the same rate as, for example, the average of all counties in the reference area composed of the five contiguous nonmetropolitan counties. In 1980, Grays Harbor County had an increasing regional share of 170 employees, indicating that its forest products industry grew faster between 1975 and 1980 than the average rate for the industry in the contiguous nonmetropolitan county reference area (table 3). This change reflects a gain in the comparative advantage of Grays Harbor County over its neighbors because areas that increase their regional shares of employment "are those in which overall access to basic inputs or to markets has been improved relative to other regions engaged in the same activity; they have gained because of their greater locational advantages for the operations of given activities or industries" (Perloff and others 1960).

The change in shares of employment shows that the economic performance of the forest products industry in Grays Harbor County also surpassed that in all the other reference areas except metropolitan Washington—where secondary processing in the forest products industry is more important—and the United States. Furthermore, if all industries are considered, the rate of change for Grays Harbor between 1975 and 1980 was higher than for all reference areas.

Table 3—Change in shares of employment of 6 reference areas, for selected industries in Grays Harbor County, 1975-80 and 1975-83

Reference area and industry	1975-80	1975-83
	Employees 1/	
Contiguous nonmetropolitan counties: 2/		
Forest products industry	170	8
All industries	1,772	614
Western Washington:		
Forest products industry	80	-349
All industries	1,955	-883
Nonmetropolitan Washington:		
Forest products industry	235	238
All industries	3,348	1,525
Metropolitan Washington:		
Forest products industry	-268	-934
All industries	1,673	-1,357
State of Washington:		
Forest products industry	39	-308
All industries	2,155	-455
United States:		
Forest products industry	-364	-1,033
All industries	4,064	643

1/ Minus signs indicate a decreasing share.

2/ Grays Harbor, Jefferson, Lewis, Mason, and Pacific Counties.

The recession of 1981 and 1982 and the mothballing of the nuclear reactor at Satsop, Washington, are evident when the analysis is extended through 1983. Grays Harbor increased its share of all industry employment (including the forest products industry) relative to its neighbors and nonmetropolitan Washington but lost ground in most respects relative to the other reference areas. The exception was the United States. Although Grays Harbor County's share of the Nation's employment in the forest products industry declined between 1975 and 1983, its share of all-industry employment increased.

The economic vitality of Grays Harbor County compares favorably with that of other counties in the nonmetropolitan areas of Washington. Its immediate neighbors are not as well off in terms of change in regional shares of employment in the forest products industry and all industries. Furthermore, had the nuclear reactor project not been mothballed, the Grays Harbor County increase in the share of "all industries" employment would have surpassed that of all reference areas (see appendix table 7).

Comparing Profits Before Taxes

Value added by manufacturing represents income payments directly to workers and business owners. It is equal to the value of shipments less the cost of materials, parts, supplies, fuel, goods purchased for resale, electric energy, and contract work. In 1977, Grays Harbor County accounted for about 59 percent of the $538 million of the value added by the forest products industry located in Grays Harbor County and the contiguous nonmetropolitan counties (see appendix table 8). Between 1977 and 1982, the value added by the area's forest products industry decreased by 46 percent to $288 million (see appendix table 9). During this period, value added by the forest products industry in Grays Harbor County declined by 48 percent. Consequently, its share of the five-county area's value added declined slightly to 56 percent of the total.

Profit before taxes is equal to value added minus payroll (see appendix tables 8 and 9). Profit before taxes dropped precipitously between 1977 and 1982 (table 4); and in Pacific County, profits had also declined between 1972 and 1977. In 1977, profit before taxes per worker hour earned by the forest products industry in Grays Harbor County exceeded profit earned by the industry in the other four contiguous nonmetropolitan counties. Despite the slightly smaller share of value added in 1982 than in 1977, profit before taxes did not decline as much in Grays Harbor County during this period as it did in all but one of the neighboring counties. Consequently, 1982 profits before taxes were still higher in Grays Harbor County than in the other four counties.

Summary and Conclusions

During the 1975-83 period, Grays Harbor County increased its share of employment in all industries in the contiguous, five-county area. Meanwhile, growth in employment in the forest products industry in Grays Harbor County kept pace with that of neighboring counties. These trends reflect the comparative advantage of Grays Harbor County over its neighbors. Furthermore, in 1977 and 1982, profits before taxes were higher for the forest products industry in Grays Harbor County than in neighboring counties. Also, profits increased faster in Grays Harbor County between 1972 and 1977 than in neighboring counties and declined less between 1977 and 1982.

The results of this analysis suggest that during the 1975-83 period, the forest products industry and dependent communities in Grays Harbor County were better off than those in neighboring counties. Grays Harbor County responded more than its neighbors did to the economic opportunities during the upswing of the business cycles of the 1970's and, as a consequence, has better withstood the stresses brought on by the collapse of the housing market and subsequent recession.

The Grays Harbor Sustained Yield Unit was established to enhance the economic performance of the forest products industry and dependent communities in Grays Harbor County. When it was established, the unit's exclusionary timber allocation policy may have had little or no impact on the economies of neighboring counties. Currently, however, the unit may have an adverse economic impact on the timber industry located outside Grays Harbor County. Furthermore, the unit may be one reason (albeit minor) why Grays Harbor County surpassed its neighbors in economic performance between 1975 and 1983.

Table 4—Profit before taxes per worker hour in the forest products industry in Grays Harbor, Washington, and contiguous nonmetropolitan counties, 1977 and 1982

County and industry	Profits before taxes 1/			
	1977	Change between 1972 and 1977	1982	Change between 1977 and 1982
	1977 dollars per hour	Percent	1977 dollars per hour	Percent
Grays Harbor:				
Lumber and wood products	17.13	113.80	11.10	-35.21
Paper and allied products	16.52	57.73	13.24	-19.85
Jefferson:				
All manufacturing, including paper and allied products 2/	14.14	39.21	8.81	-37.74
Lewis:				
Lumber and wood products	10.73	20.27	10.26	-4.38
Mason:				
Lumber and wood products	10.08	52.32	-3.98	-139.49
Pacific:				
Lumber and wood products	7.08	-34.68	2.88	-59.38
All contiguous counties:				
Lumber and wood products	13.61	63.13	7.65	-43.77
Paper and allied products	15.57	50.57	11.07	-28.90
Average	13.90	59.95	8.27	-40.51

1/ Profit before taxes equals value added minus payroll divided by hours worked.

2/ Paper and allied products accounts for most of the manufacturing in Jefferson County.

Source: U.S. Bureau of the Census, Census of Manufactures, for 1977 and 1982, States of the Pacific Northwest, the South, and the United States, available in 1980 and 1985, respectively.

The timber allocation policy of the Grays Harbor Sustained Yield Unit discriminates against potential bidders representing processors from neighboring counties. We have shown that Grays Harbor County exhibits more economic vitality than its neighbors. Shielding a well-off county to the detriment of its less well-off neighbors may not explicitly conflict with the intent of the Cooperative Sustained-Yield Act. Evidence suggests, however, that the Forest Service may wish to determine whether, from the standpoint of equity, the preferential treatment granted to Grays Harbor County can be justified. Furthermore, since the economy of Grays Harbor County continues to outperform that of its neighbors, there seems to be no reason to rescind the 1981 decision to incrementally reduce the unit's primary processing restrictions—by 1986—from 100 percent to 50 percent of the stumpage harvested from the Quinault Ranger District.

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Appendix 1
Tables 5 to 9

Table 5—Importance of timber harvested from the Grays Harbor Sustained Yield Unit, 1978-84

Year	Timber harvested		Unit's contribution as a proportion of total harvest
	From unit	From all ownerships in Grays Harbor County	
	- - - - Million board feet - - - -		Percent
1978	92.9	528.3	17.6
1979	85.1	595.7	14.3
1980	76.4	409.7	18.6
1981	49.5	337.5	14.7
1982	49.2	589.1	8.4
1983	100.6	948.4	10.6
1984	82.7	792.1	10.4

Source: "Quarterly Cut Records," Olympic National Forest and "Timber Harvest Reports," State of Washington, Department of Natural Resources.

Table 6—Volume of timber harvested from the Grays Harbor Sustained Yield Unit, for which the requirement for processing inside Grays Harbor County was waived, 1978-85

Year	Volume processed outside county
	Million board feet
1978	2.3
1979	1.5
1980	11.0
1981	2.8
1982	7.0
1983	20.0
1984	5.0
1985	0

Source: Personal correspondence with Bill Hay, Olympic National Forest, Quinault Ranger District. During the 1981-85 period, an additional 5.2 million board feet was processed outside the unit from lands that became exempt as a result of the 1981 decision to incrementally reduce the primary processing restrictions.

Table 7—Change in shares of employment of 6 reference areas for selected industries in Grays Harbor County, Washington, 1975-80, 1980-82, 1982-83, and 1975-83

Reference area and industry	1975-80	1980-82	1982-83	1975-83
		Employees		
Contiguous nonmetropolitan counties:				
Forest products industry	170	-465	350	8
Contract construction	1,523	378	-466	672
All industries	1,772	-161	-196	614
Western Washington:				
Forest products industry	80	-726	329	-349
Contract construction	2,419	1,649	-2,526	1,009
All industries	1,955	324	-2,540	-883
Nonmetropolitan Washington:				
Forest products industry	235	-252	301	238
Contract construction	2,511	1,837	-1,948	1,248
All industries	3,348	1,324	-1,864	1,525
Metropolitan Washington:				
Forest products industry	-268	-866	238	-934
Contract construction	2,451	1,590	-2,441	1,033
All industries	1,673	166	-2,555	-1,357
State of Washington:				
Forest products industry	39	-574	263	-308
Contract construction	2,462	1,632	-2,362	1,071
All industries	2,155	548	-2,421	-455
United States:				
Forest products industry	-364	-825	180	-1,033
Contract construction	2,732	1,259	-2,613	1,139
All industries	4,064	-571	-2,592	643

Table 8—Value added, payroll, hours worked, and profit before taxes, by forest products industry in the Grays Harbor and contiguous nonmetropolitan counties in Washington State, 1977

County and industry	Value added	Payroll	Hours worked	Profit before taxes 1/	
				1977	Change between 1972 and 1977
	Million 1977 dollars		Million	1977 dollars per hour	Percent
Grays Harbor:					
Lumber and wood products	257.5	87.9	9.9	17.13	113.81
Paper and allied products	59.1	24.4	2.1	16.52	57.73
Jefferson: 2/					
All manufacturing	32.7	12.9	1.4	14.14	39.21
Lewis:					
Lumber and wood products	117.7	51.2	6.2	10.73	20.27
Mason:					
Lumber and wood products	51.1	24.9	2.6	10.08	52.32
Pacific:					
Lumber and wood products	19.5	11.0	1.2	7.08	-34.68
All contiguous counties:					
Lumber and wood products	445.8	175.0	19.9	13.61	63.13
Paper and allied products	91.8	37.3	3.5	15.57	50.57
Total or average	537.6	212.3	23.4	13.90	59.95

1/ Profit before taxes equals value added minus payroll divided by hours worked.

2/ Paper and allied products accounts for most of the manufacturing in Jefferson County.

Source: U.S. Bureau of the Census, Census of Manufactures, for Washington State, 1972 and 1977; available in 1976 and 1980, respectively.

Table 9—Value added, payroll, hours worked, and profits before taxes, by forest products industry in the Grays Harbor and contiguous counties, Washington, 1982

County and industry	Value added	Payroll	Hours worked	Profit before taxes 1/	
				1977	Change between 1977 and 1982
	Million 1977 dollars		Million	1977 dollars per hour	Percent
Grays Harbor:					
Lumber and wood products	124	58	6.0	11.10	-35.21
Paper and allied products	38	18	1.5	13.24	-19.85
Jefferson: 2/					
All manufacturing	24	13	1.3	8.81	-37.74
Lewis:					
Lumber and wood products	79	39	3.9	10.26	-4.38
Mason:					
Lumber and wood products	13	22	2.2	-3.98	-139.49
Pacific:					
Lumber and wood products	10	7	1.1	2.88	-59.38
All contiguous counties:					
Lumber and wood products	226	125	13.2	7.65	-43.77
Paper and allied products	62	31	2.8	11.07	-28.90
Total or average	288	156	16.0	8.27	-40.51

1/ Profit before taxes equals value added minus payroll divided by hours worked.

2/ Paper and allied products accounts for most of the manufacturing in Jefferson County.

Source: U.S. Bureau of the Census, Census of Manufactures, for Washington State, 1977 and 1982; available in 1980 and 1985, respectively.

Appendix 2
Washington Counties by Reference Areas

Reference area	Counties
Contiguous nonmetropolitan counties	Grays Harbor, Jefferson, Lewis, Mason, Pacific
Western Washington	Clallam, Clark, Cowlitz, Grays Harbor, Island, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Pierce, San Juan, Skagit, Skamania, Snohomish, Thurston, Wahkiakum, Whatcom
Metropolitan Washington	Benton, Clark, Franklin, King, Kitsap, Pierce, Snohomish, Spokane, Thurston, Whatcom, Yakima
Nonmetropolitan Washington	Adams, Asotin, Chelan, Clallam, Columbia, Cowlitz, Douglas, Ferry, Garfield, Grant, Grays Harbor, Island, Jefferson, Kittitas, Klickitat, Lewis, Lincoln, Mason, Okanogan, Pacific, Pend Oreille, San Juan, Skagit, Skamania, Stevens, Wahkiakum, Walla Walla, Whitman

Schallau, Con H; Maki, Wilbur R. Are Federal sustained yield units equitable? A case study of the Grays Harbor unit. Res. Pap. PNW-369. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 17 p.

The Grays Harbor Federal Sustained Yield Unit (U.S. Department of Agriculture, Forest Service) was established in 1949 to enhance the economic stability of the forest products industry and dependent communities in Grays Harbor County, Washington. Provisions of the unit's charter require that all logs harvested from the Quinault Ranger District of the Olympic National Forest receive primary processing in Grays Harbor County. Periodic reviews have resulted in few changes in the operation of the unit. In 1981, however, restrictions were incrementally relaxed so that by 1985, only 50 percent of the logs had to be processed in Grays Harbor County. This paper describes an analysis that was part of a review to determine whether the 1981 change should be continued or rescinded. Findings of this study suggest that the forest products industry and the economy in Grays Harbor County are healthier than in the contiguous nonmetropolitan counties and that continuing the restriction may be to the detriment of neighboring counties that are not as well off.

Keywords: Sustained yield, economic impact, economics (forest products industries), community stability.

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Natural Regeneration 10 Years After a Douglas-Fir Tussock Moth Outbreak in Northeastern Oregon

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Abstract

Wickman, B.E.; Seidel, K.W.; Starr, G. Lynn. Natural regeneration 10 years after a Douglas-fir tussock moth outbreak in northeastern Oregon. Res. Pap. PNW-RP-370. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 15 p.

A survey of natural regeneration 10 years after severe grand fir mortality caused by an outbreak of Douglas-fir tussock moth was conducted in the Wenaha-Tucannon Wilderness in the Blue Mountains of northeastern Oregon. Seedling stocking was only moderate, but seedling density was adequate where present. Grand fir is dominating both preoutbreak and postoutbreak regeneration, but ponderosa pine has increased substantially over preoutbreak levels. The largest seedlings are larch, spruce, and pine. These species have the fastest juvenile growth rate and also were not severely defoliated during the outbreak. Certain environmental factors affecting regeneration did not produce strong correlations other than some obvious relations like distance to nearest seed tree. There was a weak positive relation of regeneration density with the presence of litter. Given the past and present management regimes for this area, the pattern of gradual stand dominance by grand fir is the result of natural succession and lack of ground fires. Within a hundred years, history will probably repeat itself with a severe tussock moth outbreak that again reduces the grand fir component of the stand.

Keywords: Regeneration (stand), Douglas-fir tussock moth, *Orgyia pseudotsugata*, grand fir, *Abies grandis,* regeneration (natural), mixed stands, Blue Mountains-Oregon, Oregon (Blue Mountains), insect damage-forest.

Summary

Natural regeneration was surveyed 10 years after severe grand fir mortality caused by an outbreak of the Douglas-fir tussock moth in the Blue Mountains of northeastern Oregon. The study plots were located in the Wenaha-Tucannon Wilderness. Management influences have been limited to grazing cattle and excluding fire since the early 1900's. Regeneration measurements were made in a 350-acre mixed conifer stand that suffered 40-75 percent grand fir mortality immediately after the outbreak. Plots for measuring tree damage were established in 1972; the regeneration plots were located in and adjacent to these older plots.

Based on the percentage of 4-milacre subplots stocked, and on the average number of seedlings per acre for all species and ages, regeneration was moderate. There were 572 seedlings per acre and 496 were in the postoutbreak class. Sixty percent of the 4-milacre subplots were stocked with at least one seedling of any age and 54 percent were stocked with seedlings of postoutbreak age. Regeneration establishment since the outbreak has been spotty. Depending on the definition of adequate stocking, the proportion of plots successfully regenerated can be determined. If 60-percent stocking of 4-milacre subplots is considered satisfactory, then only half the plots met this criteria and the area as a whole is understocked. On the basis of seedling density, however, 67 percent of the subplots had at least 400 trees per acre and understocking is not a problem.

Grand fir, ponderosa pine, Douglas-fir, and Engelmann spruce were the most common species in that order. Stocking of ponderosa pine in the postoutbreak regeneration was 19.7 percent compared to a preoutbreak level of 0.7 percent. Douglas-fir stocking has also increased in the postoutbreak regeneration.

Species dominance has changed in the postoutbreak regeneration. Ponderosa pine has increased from 2 seedlings per acre prior to the outbreak to 92 per acre currently. The tallest or fastest growing species, during the postoutbreak period, are the nonhost Engelmann spruce, larch, and ponderosa pine in that order.

Simple correlation analyses of environmental factors affecting regeneration determined logical biological relations. For example, crown closure showed a significant positive correlation to density of grand fir and Douglas-fir regeneration, thereby reflecting the shade tolerance of these species. An unexpected relationship was the positive correlation between litter and density of regeneration. Exposed mineral soil is generally the most favorable seedbed, although true fir seedlings can become established in light to medium litter layers.

Long-term fire prevention policies have allowed natural succession to result in stand dominance by grand fir. The prevalence of this species will probably result in periodic tussock moth outbreaks.

Introduction

Beginning in 1972 and continuing into 1974, an extensive and severe outbreak of Douglas-fir tussock moth (*Orgyia pseudotsugata* McD.) (DFTM) occurred in the Blue Mountains of Oregon and Washington. Defoliation varied from barely visible to total loss of needles from the host trees—grand fir, *Abies grandis* (Dougl. ex D. Don) Lindl., and Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco. Most of the severe defoliation (greater than 75 percent of the crown defoliated) occurred in patches varying from a few to several hundred acres. Severe defoliation resulted in patches of almost complete host-tree mortality (Wickman 1978a).

Forest managers feared that natural regeneration would not be adequate to reforest the larger patch kills of grand fir and Douglas-fir and consequently planted many of the areas after clearcut and partial cut salvage logging (Seidel and Head 1983). After the outbreak there were also questions about adequacy, timing, and species of natural regeneration and on environmental factors responsible for success or failure of regeneration establishment.

The status of regeneration and factors affecting establishment of seedlings on partial cuts several years after the tussock moth outbreak are reported by Seidel and Head (1983). They found that partial cuts in the mixed conifer/pinegrass community had considerably fewer seedlings than partial cuts in the grand fir/big huckleberry community which were well stocked. Much of the understocking in the mixed conifer stands was apparently related to low and irregular overstory density, lack of advance reproduction, reproduction destroyed by logging, and heavy grass cover.

Heavy grand fir mortality after tussock moth defoliation in a mixed-conifer stand in the Wenaha-Tucannon Wilderness, Umatilla National Forest, offered the opportunity to survey natural regeneration on an unmanaged site. This area represents only one of several habitat types found in the Blue Mountains, but it was one of the most common types in the DFTM outbreak. There are many other elevation gradients and physiographic sites that suffered severe tree mortality. This area was chosen because it was undisturbed by logging, because defoliation and tree damage data were available, and because it is a good growing site that would qualify for intensive timber management in nonwilderness situations. We wanted to

evaluate the status of natural regeneration and the factors affecting its establishment 10 years after the peak of tree mortality in 1973. This paper reports the results of that study.

Objectives

The purpose of the study was (1) to quantitatively evaluate natural regeneration in an undisturbed stand severely damaged by DFTM in 1972 and 1973, (2) to evaluate the condition of the residual overstory at the end of the 10-year period, and (3) to identify environmental factors related to success or failure of regeneration establishment.

Specific objectives were (1) to estimate success of regeneration in terms of stocking percentage and density (number per acre); (2) to determine species composition of the regeneration; (3) to measure regeneration stocking of preoutbreak (advance) and postoutbreak (subsequent) origin and height of each class; (4) to examine the relations between regeneration establishment and several measurable environmental variables such as overstory density, nearest seed source, and understory vegetation; and (5) to measure survival and condition of the residual overstory.

Study Area

The study area, Grizzly Bear Ridge, is in a mixed-conifer forest type in the Wenaha-Tucannon Wilderness of the Blue Mountains of northeastern Oregon at 4,000-4,350 feet elevation (fig. 1). The ridge, a broad plateau, slopes gently to the edge of the Wenaha River canyon "breaks" with a slight southern exposure. It is bisected by a series of deep (20-30 feet), narrow draws, some of which contain

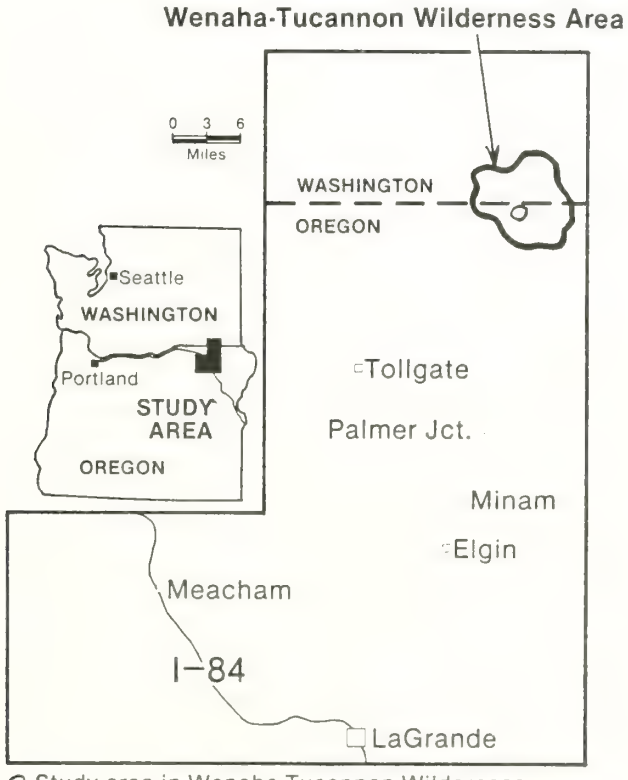

Figure 1—Location of regeneration survey in Wenaha-Tucannon Wilderness, northeastern Oregon

springs or running water. The habitat type of the stand is *Abies grandis-Pachistima myrsinites*, larch type.[1/] Preoutbreak vegetation was dominated by an overstory of grand fir and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) with a scattering of western larch (*Larix occidentalis* Nutt.) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and very few Douglas-fir. Most of the plateau (about 350 acres) was severely defoliated by tussock moth in 1972 with little additional defoliation noted in 1973. Host-tree mortality continued from 1973 to 1975 and totaled 40-75 percent (Wickman 1978a). Many of the snags resulting from this mortality have fallen and have created a heavy ground cover of logs and branches on some plots. This is also the location of a series of tree damage plots that were established in 1972 to study the effects of tussock moth outbreaks (Wickman 1978a). Some characteristics of the area sampled are given in table 1.

[1/]Identification of the plant community is based on the dominant tree overstory and on shrubs, forbs, and grasses in the understory. This habitat type was classified by S. Conrade Head in 1974. Final Report, Douglas-Fir Tussock Moth Program, on file at the Forestry and Range Sciences Laboratory, Route 2, Box 2315, La Grande, OR 97850.

Table 1—Means and ranges of plot characteristics in heavy tree mortality area, Wenaha-Tucannon Wilderness

		18 plots	
Characteristic	Unit of measurement	Mean	Range of plot means
Elevation	Feet	4,200	4,000-4,350
Aspect	Class	6	3-11
Slope	Class	.2	0-1.0
Residual living overstory:			
Trees per acre	Number	151	47-344
D.b.h.	Inches	7.7	5.0-11.2
Basal area	Square feet per acre	100	18-306
Canopy closure	Percent	15.2	0-38.8
Residual dead overstory:			
Trees per acre	Number	118	78-163
D.b.h.	Inches	12.3	9.2-17.8
Basal area	Square feet per acre	142	76-265
Seedbed:			
Litter	Percent	13.3	1.3-30.0
Logs	Percent	12.5	2.5-22.4
Litter + logs	Percent	25.6	6.3-45.0
Understory vegetation (subplots dominated by):			
Grass	Percent	26.8	
Herbage	Percent	39.2	
Woody perennial	Percent	32.4	
Total ground cover		67.4	61.9-80.0

Methods

Methodology for this study was similar to studies of regeneration in clearcuts in southwestern Oregon (Stein 1981) and in the Blue Mountains of eastern Oregon (Seidel 1979a, Seidel and Head 1983), and in shelterwood cuttings along the east side of the Cascade Range in Oregon (Seidel 1979b). Natural regeneration establishment following a small but severe DFTM outbreak in northern California was reported by Wickman (1978b). In that study it was found that white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) regeneration on the entire area 10 years after the outbreak was equal to preoutbreak levels. No measurements of regeneration were made, however, in the patches of dead trees.

Sample Selection

Regeneration sample plots were systematically located off a trail running north-south on the west half of the severely damaged stand on Grizzly Bear Ridge. Reconnaissance indicated that stand conditions were homogeneous on the plateau, but the east half was time consuming to reach because of its distance from the trail and difficult access through downed snags. Starting points for the first two regeneration sample plots were determined by the locations of two clusters of 0.02-acre plots used for determining stand damage from 1973 to 1977. The configuration of these plot clusters is described in Wickman (1978a). Sixteen additional plots to survey regeneration were systematically located to the east and north of the older study plots; the plots were never closer than 600 feet and were usually about 1,200 feet apart. Nine plots were sampled in July 1983 and an additional nine plots were sampled in July 1984.

Data Collection

Each plot was approximately 3.6 acres. A grid of 16 sample points (subplots) was located by hand compass and by pacing within each plot. Circular, 4-milacre subplots were systematically spaced at 99-foot intervals on four parallel lines 99 feet apart. Each line contained four subplots. At each sample point, subplots were examined for presence of regeneration, condition of residual overstory, understory cover, and associated environmental variables. A sample point was relocated by moving 99 feet along the line if conditions making it unsuitable for regeneration—streambeds, marshy ground, solid rock—occurred on more than one-half of a 4-milacre subplot.

On each 4-milacre subplot the total number of seedlings and saplings less than 2 inches in diameter at breast height (d.b.h.) was counted and recorded by species, age, and current condition. Regeneration was measured to the nearest centimeter for height and classed as advance (preoutbreak) if 11 years or older (12 years in the 1984 samples) and subsequent (postoutbreak) if 10 years or younger (11 years in the 1984 samples) by counting whorls.

Dominant type of understory vegetation cover (grass, herbaceous, and woody perennials) was noted for each 4-milacre subplot.

A concentric 0.02-acre circular plot was also established at each sample point to determine residual overstory condition. On each of these plots, tree species and d.b.h. were tallied for all standing overstory trees, including trees that died during the regeneration period. Windthrown trees and trees that died and fell during the regeneration period were also counted. The following environmental factors associated with each 4-milacre subplot were observed and recorded: [2/] aspect, slope, litter, litter and logs, canopy closure, ground cover, and dominant ground cover.

[2/] See appendix for details of procedures for measuring and coding the environmental factors.

Data Analysis

To illustrate the status of reforestation, we summarized data in tables showing the percentage of regeneration stocking and the density level of 4-milacre subplots by species and origin (preoutbreak or postoutbreak). Stocking data were summed and the means and standard errors calculated to ascertain current status of regeneration on a per-acre basis.[3/]

To determine the relationship between regeneration and environmental variables, correlation coefficients between dependent and independent variables were calculated. Dependent variables (Y) were stocking percentages of 4-milacre subplots and number of seedlings per acre of the various species. Independent variables (X) were the environmental factors listed in the appendix.

Results and Discussion

Regeneration Stocking and Density

Based on the percentage of 4-milacre subplots stocked and average seedling numbers per acre for all species and ages, regeneration was moderate.[4/] There were 572 seedlings per acre and most of these (496 seedlings per acre) were in the postoutbreak age class (table 2). Sixty percent of the 4-milacre subplots were stocked with at least one seedling of any age, and 54 percent were stocked with postoutbreak-aged seedlings. In 1972 and 1973 there was high mortality of regeneration due to defoliation (Wickman 1978a) and the pattern of stocking by age class reflects this situation. Furthermore the postoutbreak regeneration distribution was clumpy and highly dependent on proximity of seed trees. Most of the seedlings apparently became established 2 or 3 years after the outbreak-caused mortality as evidenced by the age of current stocking.

The individual plot averages of seedling density and stocking indicate that regeneration establishment since the tussock moth outbreak has been spotty; some acres are not well stocked and others contain clumps of seedlings. Plots were grouped by the number and percentage that attained specific levels of stocking or density to get a better picture of the status of regeneration (table 3). All but one plot had at least 200 trees per acre, and 67 percent of the plots contained 400 or more trees per acre.

Depending on the definition of adequate stocking, the proportion of plots successfully regenerated can be determined. If 60-percent stocking of 4-milacre subplots is considered satisfactory, then only half the plots met this criterion and the area as a whole is understocked. On the basis of seedling density, however, 67 percent of the plots had at least 400 trees per acre and understocking was not a problem.

Species Composition of Regeneration

Grand fir, ponderosa pine, Douglas-fir, and Engelmann spruce were the most common species in that order (table 4). Western larch was found on 2.8 percent of the subplots and did not appear to be an important component of the regeneration. Stocking of ponderosa pine (a nonhost species) in the postoutbreak regeneration was 19.7 percent compared to the preoutbreak level of 0.7 percent. This species is apparently regenerating better after heavy grand fir mortality and may become a more important component of the future stand. Douglas-fir was also a rare species before the outbreak but now is found on 13 percent of the subplots.

[3/]Subplots were considered stocked if they contained at least one seedling.

[4/]Stocking classes, as defined by the Pacific Northwest Seeding and Planting Committee (Reynolds and others 1953): well stocked, 70-100 percent; moderately stocked, 40-69; poorly stocked, 10-39; and nonstocked, 0-9

Table 2—Average stocking percent and number of seedlings per acre of all species in heavy tree mortality area, by regeneration class, Wenaha-Tucannon Wilderness [1/]

Regeneration class	Number of plots	Mean + SE [2/]	Range
		Stocking percent	
Preoutbreak	18	17.6 ± 2.6	0-37.5
Postoutbreak	18	54.1 ± 3.1	25-75.0
Any age	18	60.2 ± 3.1	37.5-87.5
		Number of seedlings	
Preoutbreak	18	76 ± 15	0-219
Postoutbreak	18	496 ± 76	94-1,359
Any age	18	572 ± 76	141-1,406

1/ Based on 4-milacre plots.

2/ SE = standard error.

Table 3—Proportion of plots stocked at various levels with preoutbreak and postoutbreak regeneration in a heavy tree mortality area, Wenaha-Tucannon Wilderness

Stocking			Trees per acre		
Minimum percent	Number of plots	Percent of total	Minimum number	Number of plots	Percent of total
20	18	100	200	17	94
40	17	94	400	12	67
60	9	50	600	8	44
80	2	11	800	4	22
			1,000	1	6
			1,200	1	6
			1,400	1	6

Table 4—Average stocking of preoutbreak and postoutbreak regeneration, by species, in a heavy tree mortality area, Wenaha-Tucannon Wilderness

Regeneration class	Grand fir	Douglas-fir	Ponderosa pine	Western larch	Engelmann spruce	All species [1/]
			Stocking percent ± SE [2/]			
Preoutbreak	14.2 ± 2.6	1.4 ± 0.6	0.7 ± 0.7	0.7 ± 0.5	2.3 ± 1.0	17.6 ± 2.6
Postoutbreak	39.8 ± 2.8	11.7 ± 2.0	19.7 ± 3.2	2.5 ± .7	7.9 ± 1.8	54.1 ± 3.1
Any age	47.2 ± 2.4	13.1 ± 2.2	20.4 ± 3.5	2.8 ± .8	8.9 ± 1.8	60.2 ± 3.1

1/ Totals not additive as more than one species or age class can occur on a subplot.

2/ SE = standard error.

Dominant Species

In addition to regeneration estimates based on measurements of seedling stocking and density, the species and age of the largest or most vigorous seedling on each stocked 4-milacre subplot were recorded. These data provide insight to potential species dominance in the future stand. Preoutbreak or oldest seedlings were dominant on about one-quarter of the stocked subplots; the seedlings were primarily grand fir and Engelmann spruce (table 5).

Stocking of preoutbreak grand fir is lower than it might be because of mortality from defoliation in 1972-73. Seedlings originating after the outbreak were dominant on about three-quarters of the stocked subplots. The most dramatic change since the outbreak is the increasing dominance of ponderosa pine.

Another way of looking at importance of species in the developing stand is to compare the number of seedlings per acre by species and age class. When examined this way, grand fir appears to dominate the developing stand in the preoutbreak age class (59 trees per acre) and in the postoutbreak class and at all ages (305 and 364 trees per acre, respectively) (table 6). Ponderosa pine seedlings have greatly increased since the outbreak from 2 per acre prior to the outbreak to 92 per acre currently, indicating that pine may be assuming a greater importance in future stand composition.

Seedling height is a third way of examining dominance. The tallest average regeneration of any age class is Engelmann spruce (64 inches) followed by western larch (61 inches)—both nonhost species (table 7). The tallest seedlings after the outbreak are spruce, larch, and pine; they have the greatest juvenile height growth rates and are also nonhost species.

Relation of Stocking and Density to Environmental Factors

For an assessment of the influence of observed environmental variables on density and stocking of regeneration and their relative importance, correlation coefficients were computed between each environmental variable and stocking percent and density of regeneration. The results of these analyses are presented in tables 8 and 9.

The effects that these variables have on stocking and density of regeneration depend on the species and origin of reproduction. The effect of most variables is logical and has a reasonable biological explanation. For example, crown closure showed a significant positive correlation to density of grand fir and Douglas-fir regeneration; both stocking and density of western larch regeneration were negatively correlated to overstory basal area, overstory trees per acre, or crown closure (tables 8 and 9). This relationship reflects the shade-tolerant nature of larch, which requires greater overstory disturbance for successful regeneration compared to the more shade-tolerant true fir.

Another logical relationship is the significant negative correlation between distance to seed trees and regeneration; in other words, regeneration tends to decrease as the distance to seed trees increases. We expected such a relationship because seed source in a natural regeneration setting is crucial.

Table 5—Seedling dominance, by species and age class, in a heavy tree mortality area, Wenaha-Tucannon Wilderness

Regeneration class	Grand fir	Douglas-fir	Ponderosa pine	Western larch	Engelmann spruce	All species
			Percent			
Preoutbreak	17	2	1	2	4	26
Postoutbreak	44	7	17	1	5	74
Any age	61	9	18	3	9	100

Table 6—Number of seedlings per acre, by species and age class, in a heavy tree mortality area, Wenaha-Tucannon Wilderness

Regeneration class	Grand Fir	Douglas-fir	Ponderosa pine	Western larch	Engelmann spruce	All species
Preoutbreak	59 ± 14	4 ± 2	2 ± 2	2 ± 1	9 ± 4	76 ± 15
Postoutbreak	305 ± 60	62 ± 13	90 ± 17	8 ± 3	31 ± 12	496 ± 76
Any age	364 ± 60	66 ± 13	92 ± 18	10 ± 3	40 ± 16	572 ± 76

Table 7—Average seedling height in a heavy tree mortality area, Wenaha-Tucannon Wilderness

Regeneration class	Grand fir	Douglas-fir	Ponderosa pine	Western larch	Engelmann spruce	All species
			Inches ± SE 1/			
Preoutbreak	44 ± 4	41 ± 13	25 ± 0	61 ± 2	64 ± 7	47 ± 4
Postoutbreak	15 ± 2	9 ± 3	20 ± 4	23 ± 9	26 ± 6	15 ± 2

1/ SE = standard error.

An unexpected relationship was the positive correlation between litter and density of regeneration because exposed mineral soil is the most favorable seedbed, although true fir seedlings can become established in light to medium litter layers (0.25 to 0.5 inch deep).

Observations on the plots indicated that ground cover, especially grasses and bracken fern, appeared to have a detrimental effect on seedling establishment since the outbreak. We found that grand fir in particular and even all species combined were hindered mostly by grass (table 10). This was also noted by Seidel and Head (1983) in partial cuts in the Blue Mountains following the DFTM outbreak. Correlation analyses were negative for ground cover as a whole only for western larch (tables 8 and 9).

Table 8—Significant correlation coefficients (r) between environmental variables and density of regeneration, Wenaha-Tucannon Wilderness [1/]

Species and age class	Aspect	Slope	Basal area	Trees per acre	Crown closure	Ground cover	Litter	Logs	Litter and logs	Distance to seed tree
All regeneration:	-0.37				0.50*		0.63**		0.51*	-0.40*
Grand fir	- .35		0.34		.53*		.62**		.51*	- .43*
Douglas-fir			.67**	0.61**	.69**		.49*	-0.33		- .59**
Ponderosa pine							.42*		.50*	
Western larch			- .43*	- .48*	- .34	-0.36				
Engelmann spruce			- .35							
Precutbreak:										
Grand fir										
Douglas-fir			.34		.41*	.40*	.32			
Ponderosa pine										
Western larch										
Engelmann spruce	- .37	0.42*								
Postoutbreak:	- .33				.49*		.68**		.56**	- .37
Grand fir	- .33				.50*		.67**		.57**	- .37
Douglas-fir			.64**	.59**	.65**		.46*	- .35		- .57**
Ponderosa pine							.44*		.51*	
Western larch			- .35	- .40		- .50*				
Engelmann spruce			- .34							

1/ Correlation coefficients with no asterisk are significant at the 10-percent probability level; 1 asterisk—5-percent level; 2 asterisks—1-percent level.

Table 9—Significant correlation coefficients (r) between environmental variables and stocking of regeneration, Wenaha-Tucannon Wilderness [1/]

Species and age class	Aspect	Slope	Basal area	Trees per acre	Crown closure	Ground cover	Litter	Logs	Litter and logs	Distance to seed tree
All regeneration:										-0.38
Grand fir	-0.42*									- .54**
Douglas-fir			0.42*		0.41*					
Ponderosa pine	- .39									
Western larch			- .47*	-0.57**	- .45*				-0.38	
Engelmann spruce			- .37		- .34					
Precutbreak:										
Grand fir									- .34	
Douglas-fir			.34		.41*	0.40*	0.32			
Ponderosa pine										
Western larch										
Engelmann spruce	- .32									
Postoutbreak:										
Grand fir	- .55**						.34			
Douglas-fir			.37		.33			-0.35		
Ponderosa pine	- .41*								.33	
Western larch			- .36	- .46	- .38	- .59**		- .33	- .34	
Engelmann spruce			- .36	- .34						

1/ Correlation coefficients with no asterisk are significant at the 10-percent probability level; 1 asterisk—5-percent level; 2 asterisks—1-percent level.

Table 10—Dominant ground cover on subplots related to postoutbreak seedling establishment, Wenaha-Tucannon Wilderness

Item	Grass	Herbaceous	Woody perennial	Other
Number of subplots	82	120	99	5
Number of grand fir seedlings per subplot	.57	1.59	.99	5.8
Number of seedlings (all species) per subplot	1.23	2.51	1.69	6.8

Table 11—Overstory stand composition, by species, in a heavy tree mortality area, Wenaha-Tucannon Wilderness

Trees	Grand fir	Douglas-fir	Ponderosa pine	Western larch	Engelmann spruce	All species
			Trees per acre			
Alive	122.3	3.8	6.6	11.2	7.1	151.0
Dead	115.4	1.4	.4	.6	.5	118.3
Total	237.7	5.2	7.0	11.8	7.6	269.3
			Basal area (square feet per acre)			
Alive	56.6	.4	30.0	10.1	2.8	99.9
Dead	139.2	.6	1.1	.5	.3	141.7
Total	195.8	1.0	31.1	10.6	3.1	241.6

Overstory Composition and Mortality

Natural regeneration establishment after severe tree mortality is generally dependent on the condition and composition of the overstory. For example, overstory grand fir dominated both in trees per acre with 122 live and 115 dead, and in basal area, with 57 square feet per acre alive and 139 square feet per acre dead (table 11). This resulted in a corresponding dominance of the postoutbreak regeneration by grand fir. Ponderosa pine had a live basal area of 30 square feet per acre and dead basal area of 1 square foot per acre, indicating the scattered large pine have been an important seed source for the postoutbreak natural regeneration. Only a few small Douglas-fir per acre were present in the overstory within the study area, but postoutbreak regeneration was much greater than would be expected from this limited seed source. Apparently seed trees around the perimeter of the area provided much of the Douglas-fir seed for this regeneration.

Conclusions

The establishment of natural regeneration on Grizzly Bear Ridge after severe tree mortality due to the 1972-74 DFTM outbreak was moderate. Half the study plots were understocked based on a 60-percent stocking criterion. Distribution of regeneration was clumpy. Seedling density was adequate, however, as 67 percent of the plots had at least 400 trees per acre.

Seedling dominance, as indicated by species composition, age class, and height, has undergone some changes. Before the outbreak, regeneration was dominated by grand fir. Because that species suffered heavy defoliation and resulting mortality of both the overstory and regeneration, other species are increasing in number and size. Grand fir is still the dominant species as measured by subplot stocking and seedlings per acre, but the number of pine seedlings per acre has increased dramatically since the outbreak.

The tallest seedlings are the three species with the fastest juvenile height growth that were not severely defoliated by DFTM. Postoutbreak pine and larch regeneration, being less shade tolerant, have had more open growing conditions after many of the fir overstory trees were killed. This advantage may decline as grand fir regeneration grows and canopies begin to close.

The environmental conditions with obvious biological explanations, such as proximity of seed source and the relation of crown closure to shade-tolerant fir, related to regeneration success or failure. Observations on the plots indicated grasses inhibited regeneration establishment, as reported by Seidel and Head (1983) in a similar study. However, statistical analyses did not show a negative correlation for ground cover that included grass competition. One unexpected result was that litter showed a positive relation to regeneration density. The heavy tree mortality that occurred from 1972 to 1974 resulted in many downed snags 10 years later. The litter and slash accumulation from these snags was heavy on many plots, but this did not discourage regeneration. The material possibly provided shade and moisture-conserving mulch that sheltered seedlings from severe environmental effects during the critical first few years of growth. Similar relations have been found with litter and slash and natural regeneration after shelterwood cutting. Seedlings can become established in litter and slash seedbeds (Seidel 1979c).

What then is the long-term stand prognosis for this area, which suffered a severe natural perturbation a little over 10 years ago? It is too early to predict with certainty, but based on past management practices and present regeneration trends, the prior history and future scenario might be as follows: The stand, over 100 years ago, was mixed conifer, but dominated by pine. Fire prevention and control since the turn of the century have resulted in few or no ground fires and an increasing dominance by grand fir. As the fir grew, the canopy closed discouraging pine and larch regeneration. Grand fir is also a prime host of DFTM, and as available food supplies for the insect increased so did resident populations of DFTM. At some critical point, possibly because of site overstocking, lower resistance to foliage grazing by insects, and favorable climatic conditions, DFTM escaped from its natural controls and erupted into a short-term outbreak. The insect outstripped its food supply, causing heavy tree mortality, but the population crashed in the process.

Twelve years later the stand is again dominated by scattered, mature ponderosa pine, and pine regeneration is becoming an important component of the stand. But grand fir is the most prevalent species and unless a light wildfire burns in this part of the wilderness area, fir will slowly dominate and canopy closure will occur. In 70, 80, or 90 years the conditions of the site, trees, and insects will have come full circle and await the propitious combination of factors that will trigger the next DFTM outbreak and facilitate the demise of a grand fir-dominated stand in the Blue Mountains.

Acknowledgments

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Metric Equivalents

1 acre = 0.405 hectare
1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 mile = 1.61 kilometers
1 square foot = 0.0929 square meter
1 square foot per acre = 0.2296 square meter per hectare
1 tree per acre = 2.47 trees per hectare

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Appendix

Data sources, collection methods, and summation procedures used for environmental and descriptive (independent) variables.

Aspect.—One of eight compass points measured on each subplot. The method proposed by Day and Monk (1974) was used to code the aspect, and the following values assigned to compass directions: N = 14; NE = 15; E = 11; SE = 7; S = 3; SW = 2; W = 6; NW = 10. Average coded value of the subplots was used in analyses.

Slope.—Percentage of slope of each subplot was measured with a clinometer and coded as follows: 0-9 percent = 0; 10-19 percent = 1; 20-29 percent = 2; etc. Average coded value of subplots was used.

Litter.—Percentage of each subplot covered with litter was estimated to the nearest 5 percent and averaged.

Litter and logs.—The percentage of each subplot covered with litter and logs was estimated to the nearest 5 percent and averaged.

Canopy closure.—Total vegetative cover present at 4 feet and above was estimated visually to the nearest tenth of the subplot area, coded in the same way as slope values, and averaged.

Ground cover.—Total vegetative cover present below 4 feet was estimated visually to the nearest tenth of the subplot area. Estimates for individual subplots were summed and a plot average was determined.

Dominant ground cover.—Vegetative cover was classed as the predominant one of three broad types: grass, herbaceous, or woody perennial. Separately, subplots dominated by grass and herbaceous plants or woody perennials were counted and computed as a percentage of the total subplots on the plot.

Seed source.—Distance to the nearest seed tree was judged as within 50 feet or over 50 feet in 100-foot classes. The nearest 16-inch d.b.h. or larger tree with a reasonably full crown was considered a source of seed. Trees smaller than 16 inches were noted if there was evidence they had borne seed. The species of the nearest seed tree was also recorded.

Overstory trees per acre.—The numbers of standing overstory trees (living and dead) and blown down trees were recorded on 0.02-acre plots at each of the sample points, averaged, and converted to a per-acre basis.

Overstory average diameter.—The diameters at breast height of living and dead standing trees and blown down trees on each 0.02-acre were measured to the nearest inch and averaged.

Overstory basal area.—Basal area was calculated for each tree on the 0.02-acre plots from its d.b.h., and an average basal area per acre was computed.

Wickman, B.E.; Seidel, K.W.; Starr, G. Lynn. Natural regeneration 10 years after a Douglas-fir tussock moth outbreak in northeastern Oregon. Res. Pap. PNW-RP-370 Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 15 p.

A survey of natural regeneration 10 years after severe grand fir mortality caused by an outbreak of Douglas-fir tussock moth was conducted in the Wenaha-Tucannon Wilderness in the Blue Mountains of northeastern Oregon. Seedling stocking was only moderate, but seedling density was adequate where present. Grand fir is dominating both preoutbreak and postoutbreak regeneration, but ponderosa pine has increased substantially over preoutbreak levels. The largest seedlings are larch, spruce, and pine. These species have the fastest juvenile growth rate and also were not severely defoliated during the outbreak. Certain environmental factors affecting regeneration did not produce strong correlations other than some obvious relations like distance to nearest seed tree. There was a weak positive relation of regeneration density with the presence of litter. Given the past and present management regimes for this area, the pattern of gradual stand dominance by grand fir is the result of natural succession and lack of ground fires. Within a hundred years, history will probably repeat itself with a severe tussock moth outbreak that again reduces the grand fir component of the stand.

Keywords: Regeneration (stand), Douglas-fir tussock moth, *Orgyia pseudotsugata,* grand fir, *Abies grandis,* regeneration (natural), mixed stands, Blue Mountains-Oregon, Oregon (Blue Mountains), insect damage-forest.

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LOUISIANA'S Forest Products Industry: Performance and Contribution to the State's Economy, 1970 to 1980

Wilbur R. Maki, Con H Schallau, Bennett B. Foster, and Clair H. Redmond

Abbreviations

States

AL Alabama
AR Arkansas
FL Florida
GA Georgia
KY Kentucky
LA Louisiana
MS Mississippi
NC North Carolina
OK Oklahoma
SC South Carolina
TN Tennessee
TX Texas
VA Virginia

SO South
US United States

Industries

FPI Forest Products Industry
LWP Lumber and Wood Products
PAP Paper and Allied Products
WF Wood Furniture

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Abstract

Maki, Wilbur R.; Schallau, Con H; Foster, Bennett B.; Redmond, Clair H. Louisiana's forest products industry: performance and contribution to the State's economy, 1970 to 1980. Res. Pap. PNW-RP-371. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

Employment in Louisiana's forest products industry, unlike employment in the other 12 Southern States, decreased significantly between 1970 and 1980. Despite this decrease, the value added by the industry increased. The productivity of Louisiana's forest products industry ranked second among the 13 States in the South. In 1980, lumber and wood products accounted for the largest share of the industry's employment, but paper and allied products had a larger share of the earnings. In 1977, paper and allied products had higher productivity than either lumber and wood products or wood furniture.

Keywords: Forest products industries, employment (forest products industries), Louisiana.

Preface

This report briefly describes Louisiana's forest products industry—its composition, location, evolution, and relation to economic activity elsewhere in the State, the South, and the Nation.

This is one in a series of reports for each of the 13 Southern States. These reports are companions to an analysis of the interregional competition in the forest products industries of the South and the Pacific Northwest.

Estimates of employment and earnings shown in this report were derived from U.S. Department of Commerce data. All references to dollar amounts are in constant 1977 dollars.

Highlights

- Between 1970 and 1980, employment in Louisiana in the forest products industry declined by 17 percent. This decrease reflects increased technology in paper and allied products; the closure of older, more labor-intensive sawmills; and a shakeout in the southern pine plywood industry.

- Despite a reduction in employment, value added by the forest products industry increased substantially between 1972 and 1977.

- The forest products industry is one of the basic industries in Louisiana. As the importance of the oil industry grew between 1970 and 1980, the relative importance of the forest products industry declined. More recently, OPEC (Organization of Petroleum Exporting Countries) oil prices have declined and domestic exploration for and production of oil have declined significantly in Louisiana. Consequently, the importance of the forest products industry has probably increased since 1980.

- In 1977, productivity of the forest products industry in Louisiana was exceeded in the South only by Alabama. Between 1972 and 1977, productivity increased by 35 percent. This increase—third highest in the South—was achieved despite average annual wages in Louisiana being the region's highest.

- Generally speaking, the forest products industry is more important in the northern half of the State than elsewhere. For example, the forest products industry accounts for 25 percent of the economic base (that is, those industries producing for export to other States and the rest of the world) in the Monroe area, whereas the industry does not qualify as basic in the New Orleans area.

- In 1980, lumber and wood products employed the largest share of the approximately 28,000 workers in the State's forest products industry. Paper and allied products had the largest share of 1980 earnings.

- Average annual earnings in the forest products industry in Louisiana were greater than average earnings in any other State in the South and greater than the average for the United States. Furthermore, earnings increased faster in Louisiana than in either the South or the Nation.

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2 Components of the State's Economic Base
4 Geographical Importance of the State's Forest Products Industry
5 Composition of the State's Forest Products Industry
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The Forest Products Economy of Louisiana

The State's Work Force

Louisiana's estimated full- and part-time work force in 1980 was comprised of an estimated 1.8 million employees and proprietors (see appendix 1 for sources of employment and earnings data). Louisiana's work force grew considerably faster between 1970 and 1980 than did the national average (33.8 versus 22.3 percent). Total earnings—wage and salary payments and proprietorial income—grew much faster than the national average. Measured in constant 1977 dollars, the State's earnings increased by 57.6 percent compared with 27.4 percent for the Nation. As can be seen in the following tabulation, services, State and local government, retail trade, and manufacturing were the State's four largest employer categories.

	Percent of total employment, 1980	
Employers	**Louisiana**	**U.S.**
Major industries:		
Services	17.75	18.22
State and local government	14.32	12.56
Retail trade	13.84	14.18
Manufacturing (including forest products industry[1/])	11.49	19.15
Construction	7.45	4.08
Transportation, communication, and public utilities	6.73	4.84
Nonfarm proprietors	5.75	6.58
Wholesale trade	5.54	4.97
Mining	4.81	0.97
Finance, insurance, and real estate	4.02	4.95
Agriculture	4.02	4.39
Federal military	2.38	2.30
Federal civilian	1.90	2.81
Total	100.00	100.00

[1/]The forest products industry is comprised of (1) lumber and wood products (SIC 24), except mobile homes (SIC 2451); (2) wood furniture manufacturing (SIC 2511, 2512, 2517, 2521, 2541); and (3) paper and allied products (SIC 26).

Components of the State's Economic Base

Along with total employment, there is another and perhaps more important way to judge an industry's contribution to Louisiana's economy. For the State's economy to grow and develop, it must attract new dollars so residents can buy goods and services produced elsewhere. The industries that export products and services beyond local boundaries (that is, to elsewhere in the State, to other States, and to the world) and bring in new dollars, constitute the area's economic base. Generally speaking, most manufacturing employment is classified as economic base (or basic); residentiary employment (for example, barber shops, realty firms, schools, and local government) is primarily geared to producing for local needs. Some services may, however, be basic. For example, Federal military provides national defense for all the Nation's citizens, and taxpayers outside Louisiana provide financial support for this activity.

Residentiary employment is supported by the economic base. Money flowing in provides income for wage earners and entrepreneurs to spend on locally purchased goods and services. In most cases, the economic growth of a region is dependent on the success of its economic base.

We used the excess employment technique to identify the industries that comprise Louisiana's (or a sub-State district's) economic base. This approach accepts the national distribution of employment among industries as a norm. Any industry with employment in excess of this norm is considered to be producing for export markets outside the State (or sub-State district) and is part of Louisiana's economic base. The percentage of Louisiana's excess employment served as an indicator of the State's dependency on a particular industry for generating new dollars from outside the State (table 2 shows how excess employment and industry dependency indicators for Louisiana were calculated).

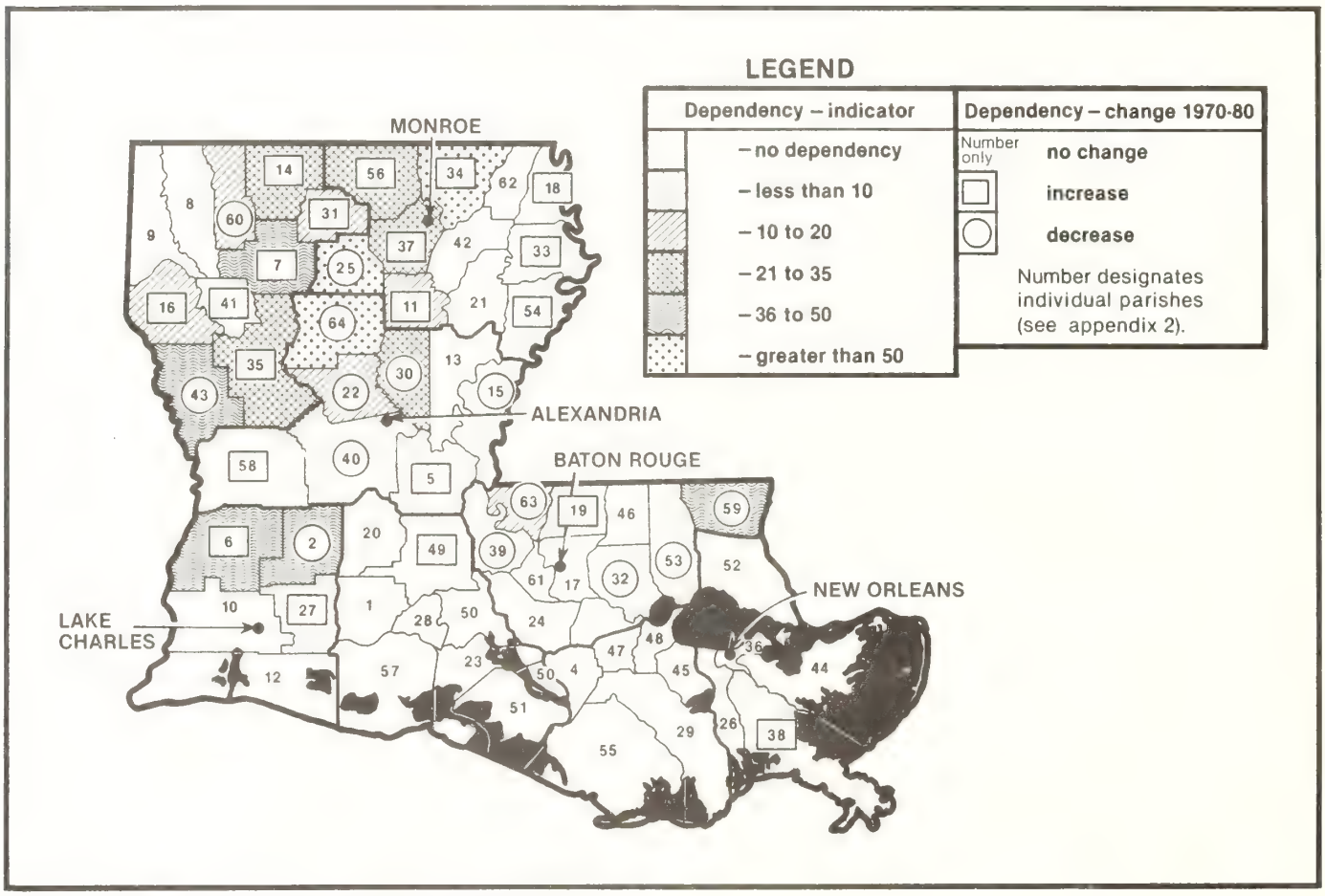
In 1980, 10 industries accounted for 94.5 percent of the State's excess employment—that is, its economic base (see tabulation below). These same industries accounted for only 82.7 percent in 1970. Furthermore, the change in shares of certain individual industries is noteworthy. In 1970, five energy-related industries—oil and gas extraction, construction, water transportation, chemical and allied products, and oil refining—accounted for about 60 percent of the State's basic employment. By 1980, they accounted for nearly 80 percent. Meanwhile, the importance of agriculture changed substantially, but in the opposite direction. Agriculture was not a basic industry in 1980; in 1970 it accounted for about 10 percent of the State's economic base employment. The relative importance of the forest products industry and Federal military components of the economic base also declined between 1970 and 1980.

More recently, OPEC (Organization of Petroleum Exporting Countries) oil prices have declined, and domestic exploration for and production of oil have declined significantly in Louisiana. Consequently, the importance of the forest products industry has probably increased since 1980.

Economic base industries	Dependency indicator	
	1970	1980
	(Percent of economic base)	
Oil and gas extraction	26.36	30.42
Construction	12.61	26.26
Water transportation	13.16	14.27
Wholesale trade	5.60	5.75
Chemical and allied products	4.38	5.65
Transportation equipment, excluding motor vehicles	1.68	3.60
Petroleum refining	3.94	3.22
Electrical, gas, and sanitation services	1.47	2.06
Forest products	7.40	2.00
Federal military	6.07	1.29
Agriculture	10.60	—
Subtotal	93.27	94.52
All other industries	6.73	5.48
Total	100.00	100.00

Geographical Importance of the State's Forest Products Industry

The contribution of the forest products industry to Louisiana's economic base varies considerably among parishes (see appendix 2 for a list of parishes). Furthermore, between 1970 and 1980, the importance of the industry increased in most parishes in the northern half of the State but declined elsewhere.



Source: Estimates for 1970 and 1980 were derived from unpublished county data series provided by the U.S. Department of Commerce, Regional Economic Information System, Washington, DC, and from the Department's *County Business Patterns*. The numbers designate parishes as coded and shown in appendix 2.

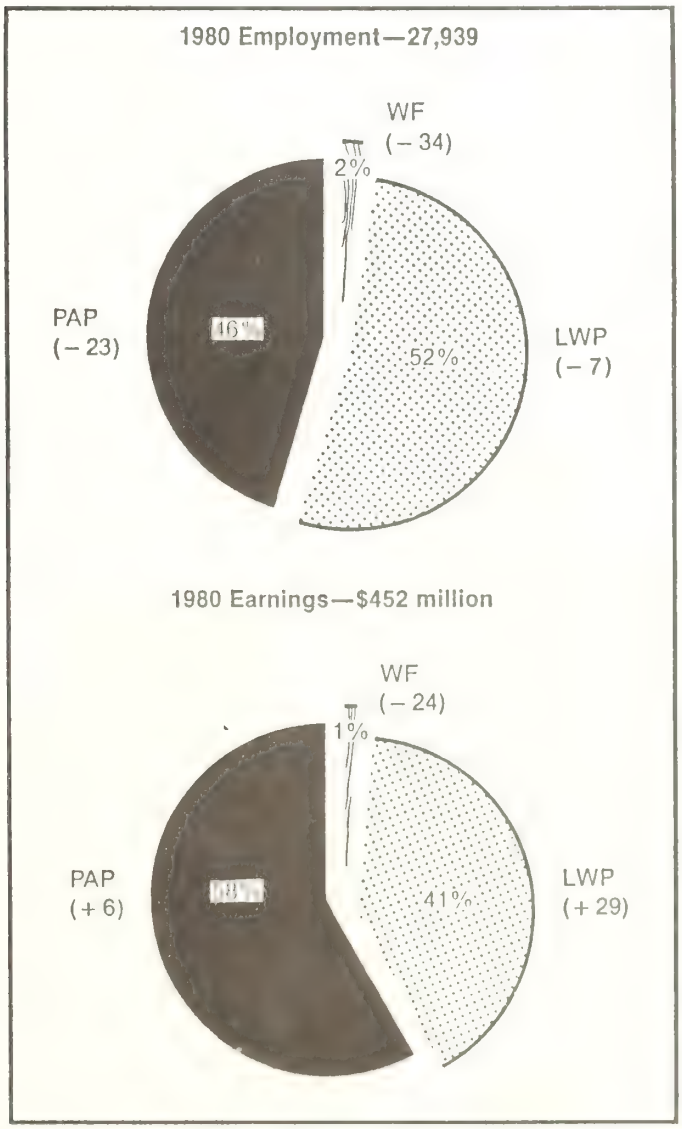
Composition of the State's Forest Products Industry

Louisiana's forest products industry is comprised of paper and allied products, lumber and wood products (not including mobile homes), and wood furniture manufacturing. Employment decreased in all three segments between 1970 and 1980. This decrease reflects increased technology in the paper and allied products (that is, the installation of more capital-intensive equipment); the closure of older, more labor-intensive sawmills; and a shakeout in the southern pine plywood industry.[2/]

In 1980, lumber and wood products employed the largest share of the approximately 28,000 workers in Louisiana's forest products industry. Paper and allied products had the largest share of 1980 earnings.

Whereas employment dropped appreciably throughout the industry, earnings increased between 1970 and 1980 in the paper and allied products and lumber and wood products segments. The wood furniture segment is the smallest; during the 1970's, its employment declined by a third while earnings declined by nearly 25 percent.

[2/]Cleaves, David A.; O'Laughlin, Jay. Forest inventory, plant location and company strategies. In: Proceedings of the 1985 Southern forest economic workers (SOFEW) workshop; 1985 March 13-15; Athens, GA. Athens GA: University of Georgia; 1985: 35-43.

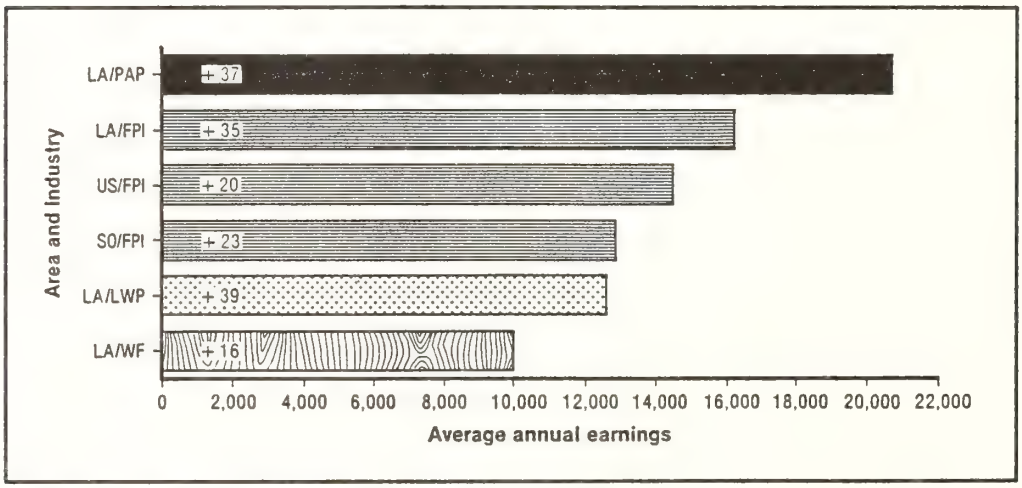


Numbers in parentheses show percentage of change from 1970 to 1980.

Average Annual Earnings per Worker

Average annual 1980 earnings per worker in paper and allied products were greater than were earnings in the other two segments of the forest products industry. Higher average skill levels, capital investment per worker, and unions account for this difference. Earnings in the wood furniture industry were less than half of those for paper and allied products and were significantly below the average for all forest products industries in the South and the United States.

The rate of growth in earnings was greater for Louisiana's forest products industry than for the South and the Nation. The difference resulted from the growth in earnings of the paper and allied products and lumber and wood products segments. The rate of change for wood furniture was less than that of the Nation and the South.

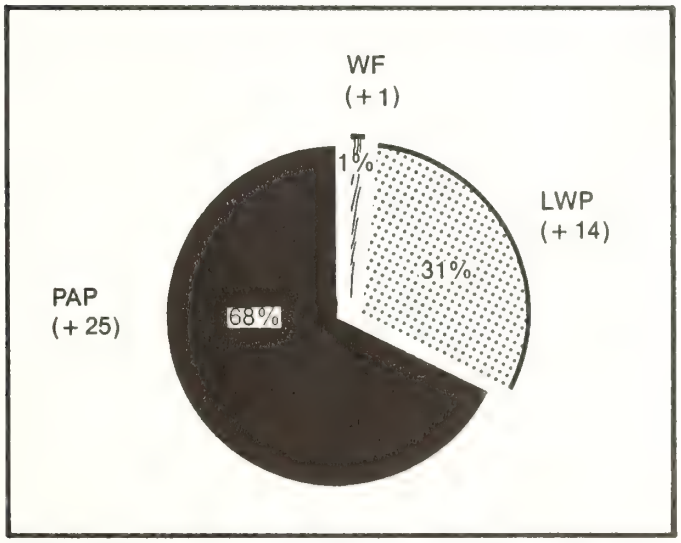


Numbers in bars show percentage of change from 1970 to 1980.

Value Added by the Forest Products Industry

Value added by manufacturing represents income payments made directly to workers and business owners. It is equal to the value of shipments less the cost of materials, parts, supplies, fuel, goods purchased for resale, electric energy, and contract work. Unlike value of shipments, value added includes only the economic contributions of the State's forest products industry. Consequently, value added by manufacturing is considered a better monetary gauge of the relative economic importance of a manufacturing industry. In 1977, paper and allied products accounted for 68 percent of the $1.02 billion of value added by Louisiana's forest products industry.

Value added by the forest products industry increased substantially between 1972 and 1977 despite declining employment. Overall, value added increased by 21 percent; paper and allied products experienced the most growth and wood furniture the least.



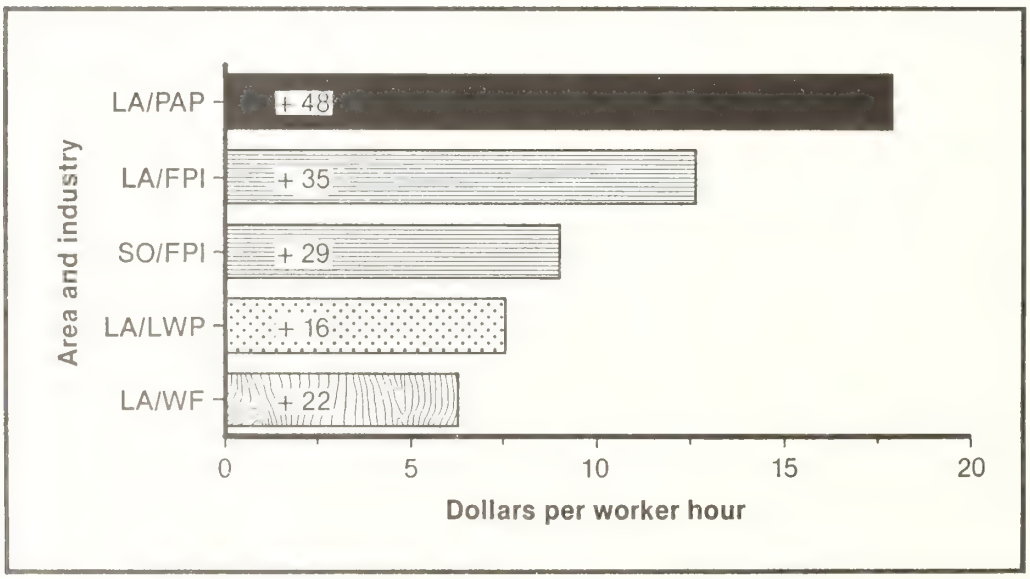
Numbers in parentheses show percentage of change from 1972 to 1977.

Capital Productivity

Increases in productivity are necessary for an industry to remain competitive in the marketplace. Productivity of an industry is measured in terms of value added minus payroll per worker hour—VAMP (see table 3 for an explanation of how productivity was calculated for Louisiana's forest products industry). This measure of productivity represents profits before taxes and adjusts for wide differences in payroll among industries.

Paper and allied products had by far the highest productivity in Louisiana's forest products industry. Productivity per worker hour was almost 40 percent greater than the average for the State's forest products industry.

Paper and allied products is more capital intensive and in the past has attracted considerable investment in new facilities and equipment. As a result, productivity in paper and allied products increased despite increased labor costs. During the mid-1970's, this segment exhibited a much larger gain in productivity than did the average for the South.



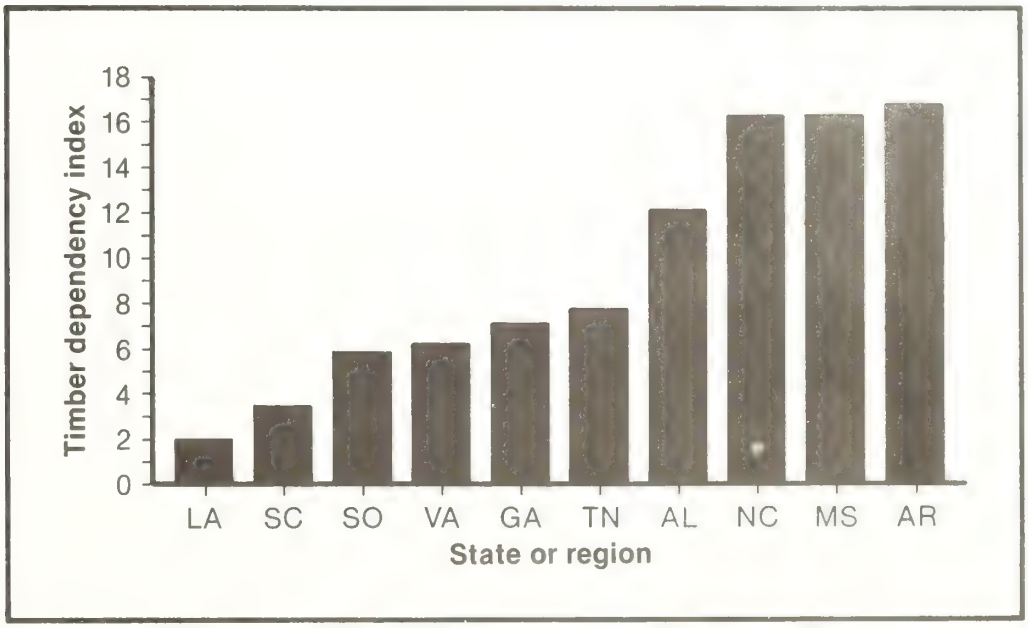
Numbers in bars show percentage of change from 1972 to 1977.

The Forest Products Industry in the South

Importance of the Industry Across the South

The dependency indicators suggest that in 1980 all but four States in the South manufactured forest products in excess of statewide needs. Oil and gas extraction, and the petrochemical industry dominate Louisiana's economy. Consequently, Louisiana is not as timber-dependent as most Southern States.

Florida, Kentucky, Oklahoma, and Texas were not self-sufficient with respect to forest products. That is, these States imported more forest products than they exported. Consequently, on net balance, their respective forest products industries did not generate new dollars from the outside. In three States—Arkansas, Mississippi, and North Carolina—the forest products industry accounts for approximately one of six basic employees. In Louisiana, 1 out of 50 basic jobs is in the forest products industry.



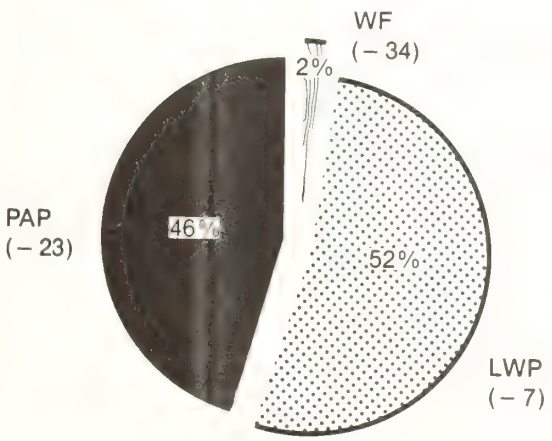
Industry Composition

Both the paper and allied products and lumber and wood products segments accounted for larger shares of 1980 employment and earnings in Louisiana's forest products industry than they did for either the South or the Nation. Unlike other Southern States, employment decreased in Louisiana during the 1970's.

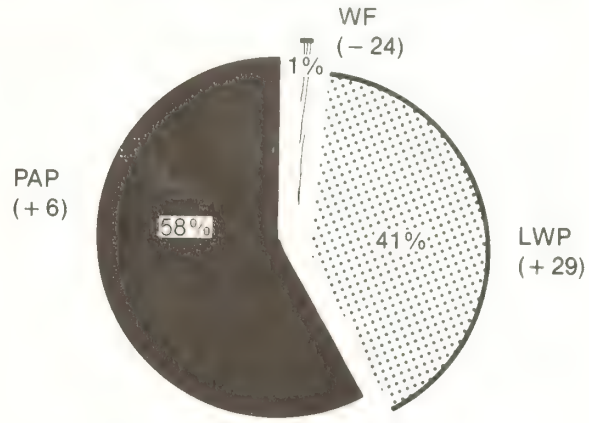
Wood furniture is much less important in Louisiana than in the South or the Nation. Furthermore, this segment's earnings and employment declined.

LOUISIANA

1980 Employment—27,939

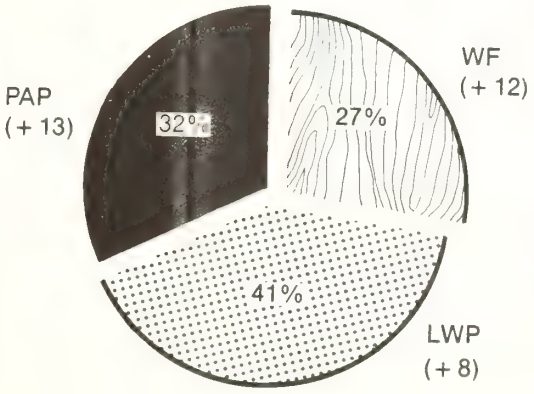


1980 Earnings—$452 million

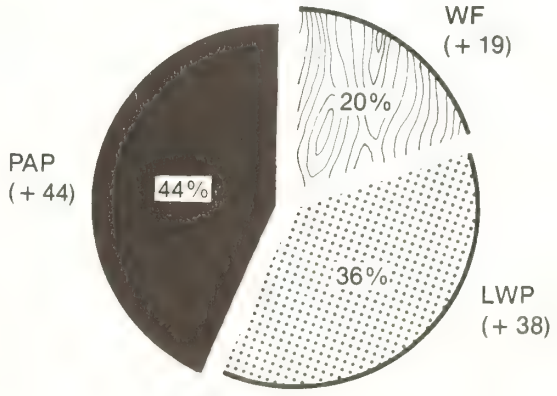


THE SOUTH

1980 Employment—620,567

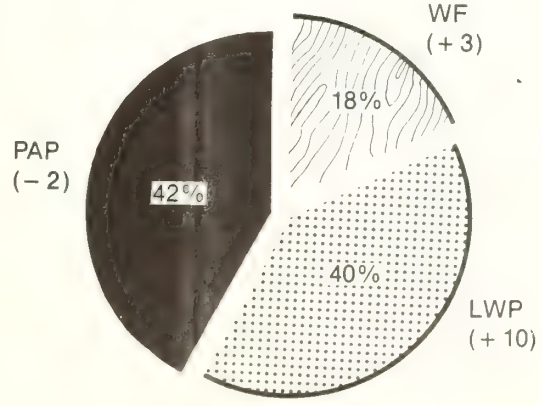


1980 Earnings—$7.96 billion

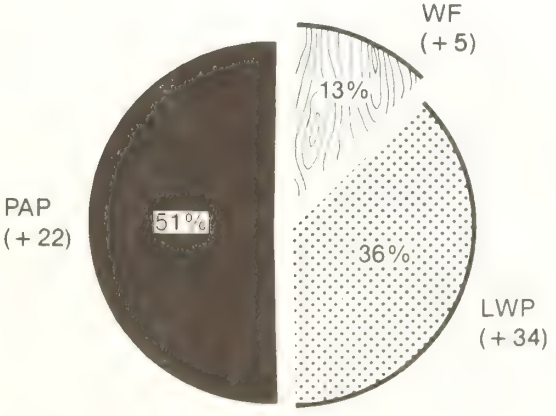


UNITED STATES

1980 Employment—1,634,000



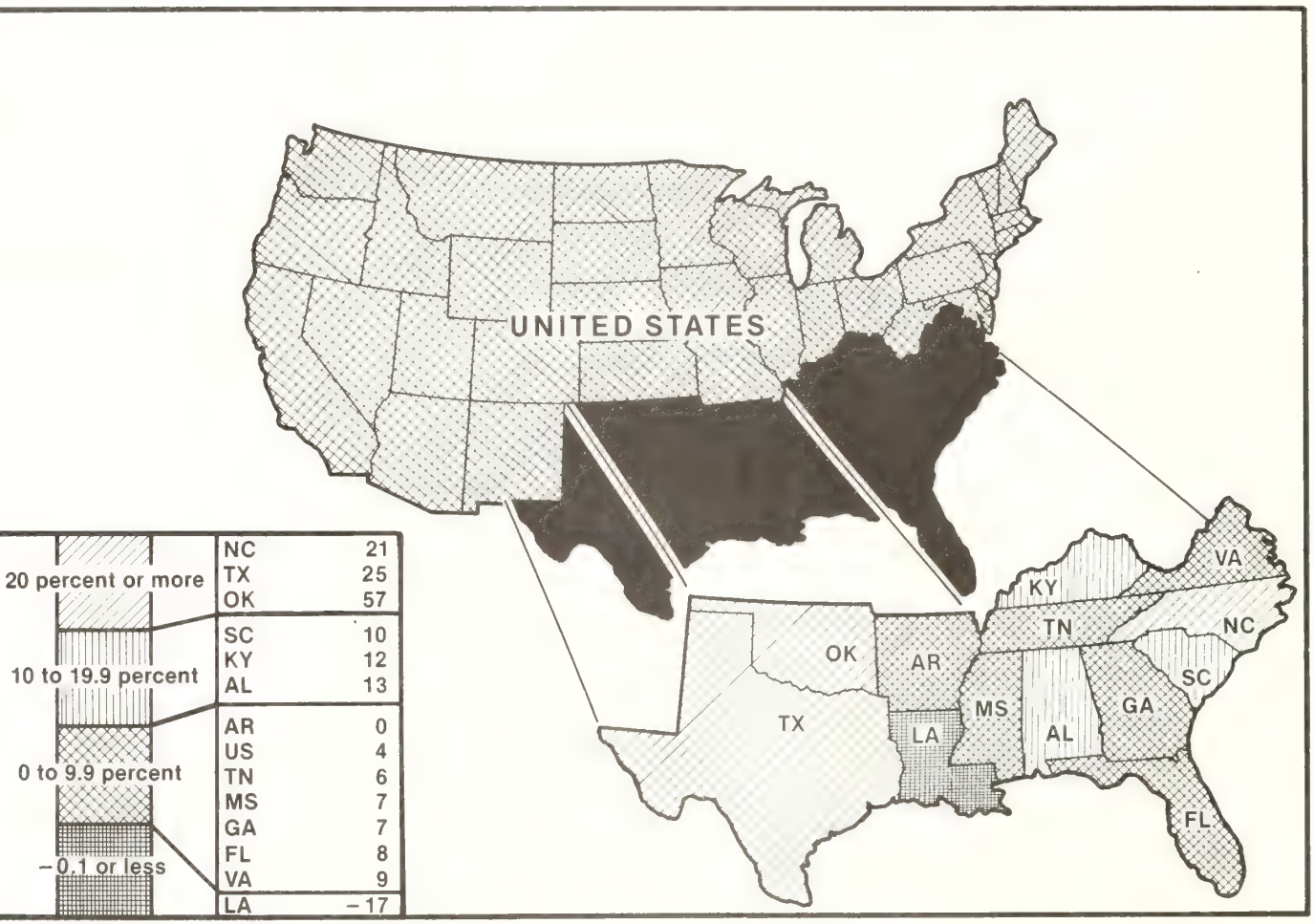
1980 Earnings—$23.65 billion



Numbers in parentheses show percentage of change from 1970 to 1980.

Growth of Employment

With the exceptions of Arkansas and Louisiana, employment in the forest products industry in each of the Southern States grew faster than did the U.S. counterpart. Between 1970 and 1980, employment in Oklahoma and Texas grew faster than the all-industry average of 22.3 percent.

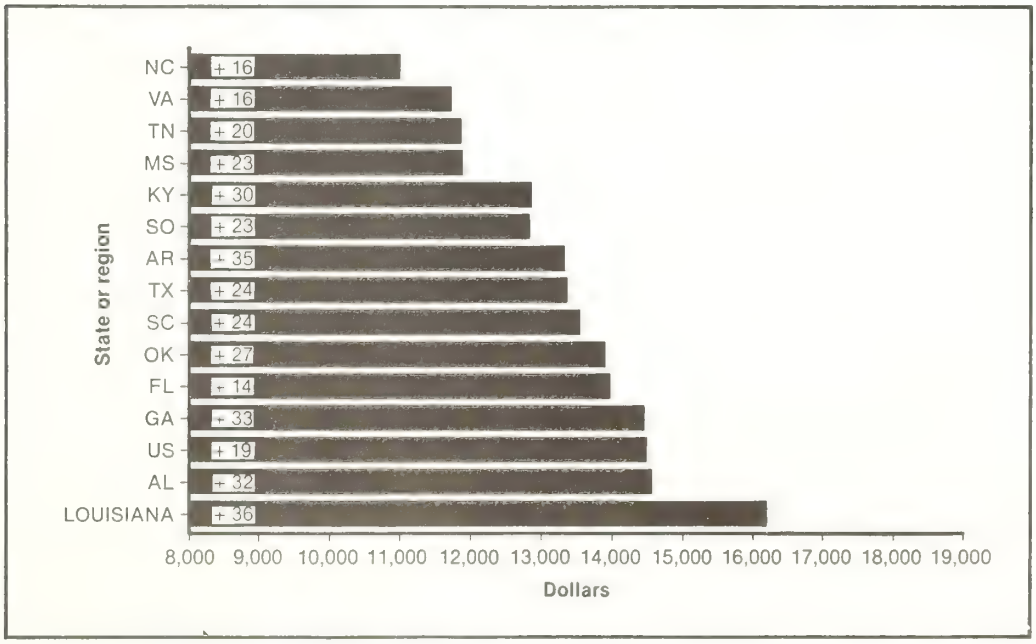


Average Annual Earnings

Average annual earnings per worker in the forest products industry differed significantly by State in 1980. Approximately $5,000 separated the State with the highest (Louisiana) from the State with the lowest (North Carolina). Pulp and allied products manufacturing, which has traditionally paid higher wages than have other segments of the forest products industry, dominated Louisiana's forest products industry. Wood furniture, which has paid lower average wages, dominated North Carolina's industry.

Average annual earnings in the forest products industry in Louisiana were greater than average annual earnings in any other Southern State and greater than the average for the United States. Furthermore, earnings increased faster in Louisiana than in either the South or the Nation.

Generally speaking, paper and allied products dominated the forest products industry in the States with the highest average annual earnings. This relationship reflects higher job skills and unions in pulp and paper manufacturing. Wages, by and large, were the lowest in States where the labor-intensive wood furniture industry was more important.



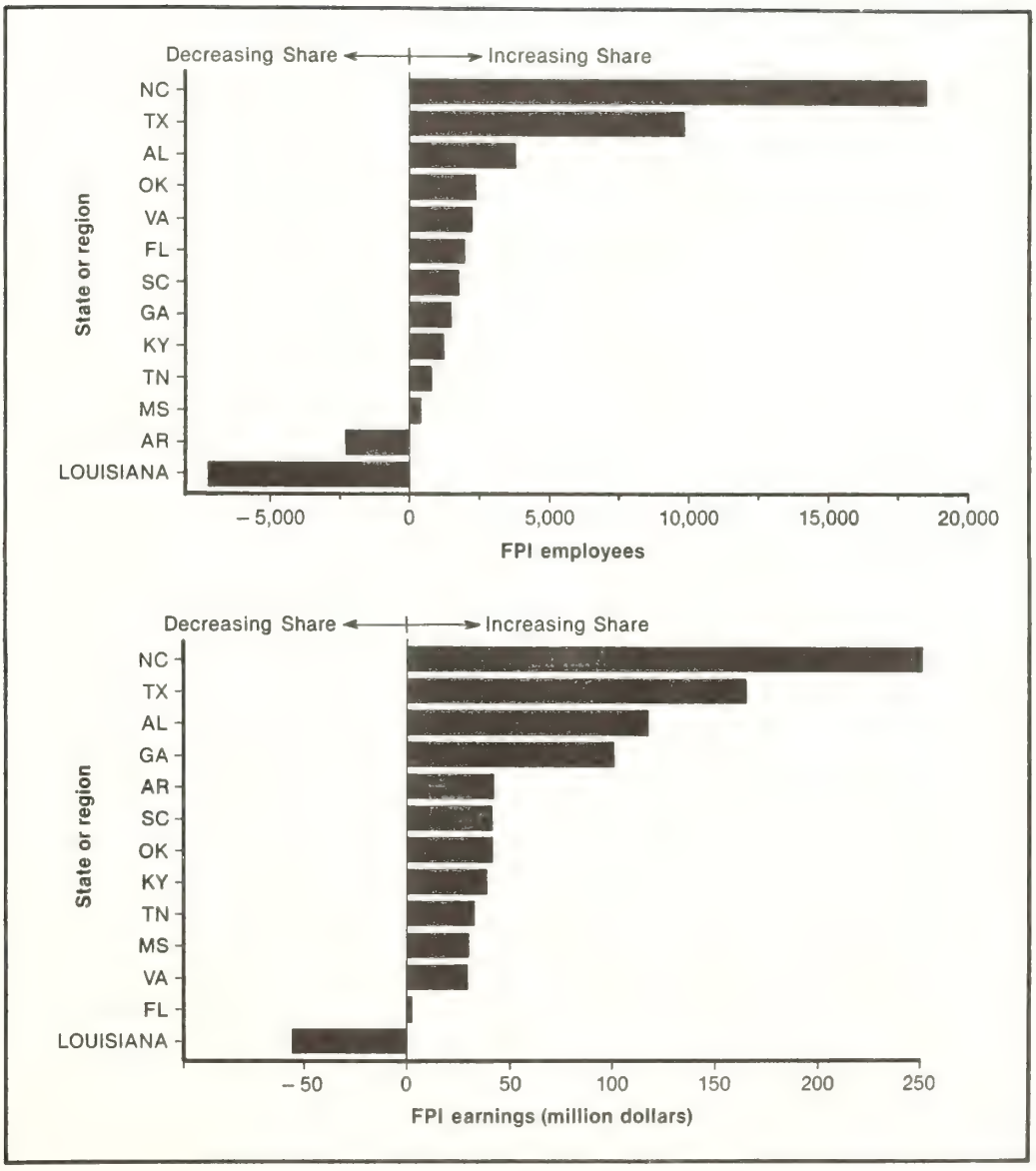
Numbers in bars show percentage of change from 1970 to 1980.

Shift in Employment and Earnings

The regional shift shows how much more or less employment and earnings a State would have had in the forest products industry in 1980 had it grown at the national rate. For example, Louisiana had about 7,200 fewer employees in 1980 than it would have had if its forest products industry had grown at the national rate.

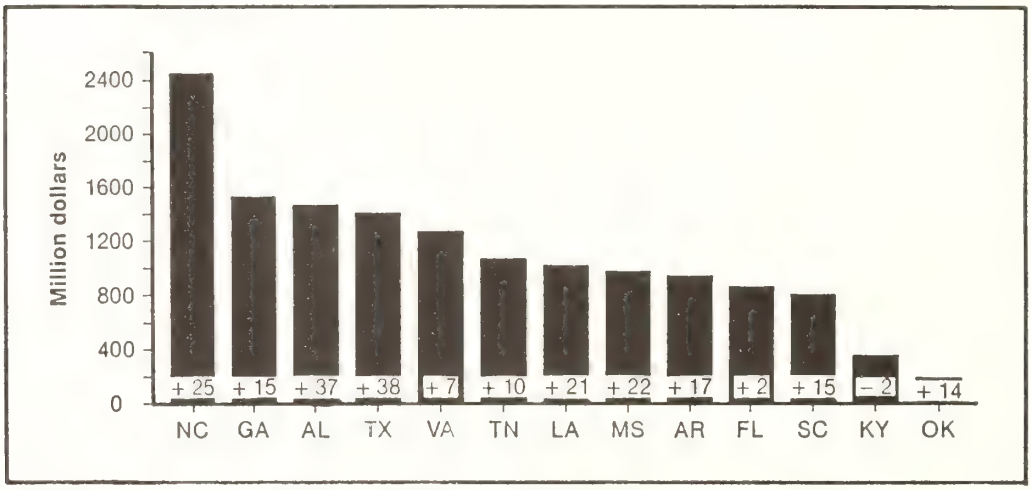
Between 1970 and 1980, employment in the forest products industry increased in every Southern State except Louisiana and Arkansas. Moreover, all but these two States increased their share of the Nation's forest products industry employment, and all but Louisiana increased their share of earnings.

Increased shares of employment and earnings reflect the comparative advantage the South's forest products industry enjoyed over this industry in the rest of the Nation. Several factors (for example, relatively lower labor costs, lower raw materials costs, and closer proximity to markets) might account for a region's comparative advantage, although adverse trends with respect to one factor need not reduce a region's advantage. For instance, increasing labor costs need not adversely affect the South's comparative advantage if increased capital or labor productivity offsets higher labor costs.


Decreasing Share
Increasing Share
State or region
NC
TX
AL
OK
VA
FL
SC
GA
KY
TN
MS
AR
LOUISIANA
– 5,000
0
5,000
10,000
15,000
20,000
FPI employees
Decreasing Share
Increasing Share
State or region
NC
TX
AL
GA
AR
SC
OK
KY
TN
MS
VA
FL
LOUISIANA
– 50
0
50
100
150
200
250
FPI earnings (million dollars)

Value Added by the Forest Products Industry

In 1977, the forest products industry of North Carolina produced more value added than any other State in the South. Georgia was second among the 13 Southern States; Louisiana was seventh. Texas not only was one of the leading States in terms of total value added but also led the South in terms of the change in value added between 1972 and 1977. Louisiana was one of only five Southern States whose change in value added exceeded that for the region (19 percent). One State, Kentucky, produced less value added in 1977 than in 1972. This can be attributed to the decline in secondary processing during the 1970's.



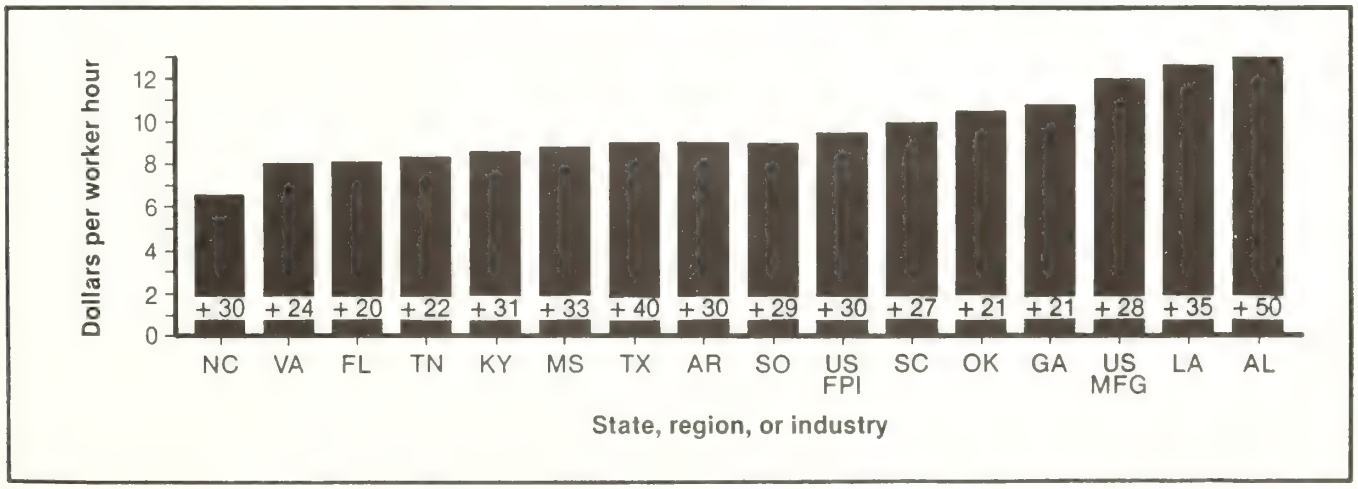
Numbers in bars show percentage of change from 1972 to 1977.

Capital Productivity

The paper and allied products segment, which is more capital-intensive and, therefore, more susceptible to technological change than are other segments of the forest products industry, exhibited the highest productivity within the forest products industry. Wood furniture, on the other hand, is the most labor-intensive of the three. North Carolina, for example, produced more value added than any other State in the South, but the productivity of its forest products industry in 1977 was the lowest. This reflects the dominant role of labor-intensive wood furniture manufacturing in North Carolina.

Increases in productivity exceeded increases in payroll per worker between 1972 and 1977 for all the Southern States. This relationship is, in part, responsible for the South's comparative advantage in the forest products industry.

In 1977, productivity of Louisiana's forest products industry was second highest of the 13 Southern States. Between 1972 and 1977, productivity increased by 35 percent. This increase—third highest in the South—was achieved despite the fact that Louisiana's average annual wages were the region's highest.



Numbers in bars show percentage of change from 1972 to 1977.

Acknowledgment

Many helpful suggestions of several reviewers were incorporated in this research paper. This project was partially funded by the USDA Forest Service Resource Program and Assessment Staff, State and Private Forestry, Area Planning and Development, State Planning for Forest Resources.

Appendix 1, Tables

Table 1—Total labor and proprietorial employment and income, by industry, Louisiana, 1980 [1/]

Industry number	Industry	Employees	Total income
		Number	*Thousand 1977 dollars [2/]*
Wage and salary			
1	Agriculture	21,365	323,565
2	Agricultural services, forestry, and fisheries	6,858	91,734
3	Coal mining	—	—
4	Oil and gas extraction	85,236	1,734,745
5	Metal mining	—	—
6	Nonmetallic minerals	3,983	64,694
7	Construction	138,092	2,216,020
8	Food and kindred products	26,640	324,563
9	Tobacco	—	—
10	Textile mill production	2,101	18,023
11	Apparel and other textiles	11,072	76,313
12	Paper and allied products	12,733	262,630
13	Printing and publishing	9,236	105,005
14	Chemical and allied products	32,734	773,937
15	Petroleum refining	13,074	397,847
16	Rubber and miscellaneous plastics	1,914	31,767
17	Leather and leather products	198	1,286
18	Lumber and wood products, excluding mobile homes	14,668	184,441
19	Mobile homes	584	7,343
20	Wood furniture	538	5,356
21	Other furniture and fixtures	335	3,335
22	Stone, clay, and glass products	8,600	124,563
23	Primary metals	7,672	162,002
24	Fabricated metals	17,016	280,715
25	Machinery, excluding electrical	12,466	214,757
26	Electrical machinery	10,714	162,995
27	Transportation equipment, excluding motor vehicles	27,537	486,850
28	Motor vehicles	765	13,307
29	Ordnance	[3/]	[3/]
30	Instruments and related equipment	1,038	14,037
31	Miscellaneous manufacturing	1,325	14,188
32	Railroad transportation	8,045	168,884
33	Trucking and warehousing	22,408	340,963
34	Local transit	4,009	56,914
35	Air transportation	6,260	126,229

See footnotes at end of table.

Table 1—Total labor and proprietorial employment and income, by industry, Louisiana, 1980 [1/] (continued)

Industry number	Industry	Employees	Total income
			Thousand 1977 dollars [2/]
Wage and salary			
36	Pipeline transportation	1,122	24,405
37	Transportation services	3,531	63,066
38	Water transportation	39,152	640,916
39	Communications	22,816	424,463
40	Electric, gas, and sanitation services	17,480	337,409
41	Wholesale trade	102,798	1,547,219
42	Retail trade	256,502	2,096,629
43	Banking	24,210	277,929
44	Other credit agencies	13,987	196,474
45	Insurance	24,112	378,212
46	Real estate and combinations	12,268	144,921
47	Hotel and other lodging	20,743	147,911
48	Personal, miscellaneous business, and repair services	74,247	859,739
49	Auto repair service	8,576	114,570
50	Amusement	9,183	61,676
51	Motion pictures	2,111	10,978
52	Private households	60,532	145,516
53	Medical and other health	74,247	987,768
54	Private education	19,581	152,456
55	Nonprofit organizations	35,397	225,355
56	Miscellaneous services	24,399	639,442
57	Federal civilian	35,202	521,434
58	Federal military	44,189	293,624
59	State and local government	265,522	2,474,124
Proprietorial			
60	Farm proprietors	46,254	243,939
61	Nonfarm proprietors	106,608	1,398,728
	Total	1,853,985	23,197,911

[1/] Source of data for this table for Louisiana, other States of the South, and the United States: unpublished data, U.S. Department of Commerce, Regional Economics Measurements Division, Regional Economic Information System (REIS), Washington, DC, 1982. Unpublished data used by the U.S. Department of Commerce in preparing their *County Business Patterns* (CBP) series on employment and payroll were used to differentiate wood-related from nonwood-related employment and earnings. For example, CBP data were used to separate mobile homes (no. 19, above) from the lumber and wood products (no. 18) industry. Wood furniture (no. 20) was similarly separated from other furniture and fixtures (no. 21).

[2/] The Personal Consumption Expenditures (PCE) deflator, 1977 = 100, was used to deflate nominal dollars

[3/] Included with fabricated metals and other related industries.

Table 2—Calculation of 1980 dependency indexes for Louisiana
(In percent)

Industry	Employment		Louisiana excess employment[1]	Dependency index[2]
	Louisiana	United States		
Agriculture	1.40	1.46	—	—
Agricultural services, forestry, and fisheries	.45	.62	—	—
Farm proprietors	3.04	3.03	0.01	0.09
Coal mining	0	.27	—	—
Oil and gas extraction	5.58	.60	4.97	30.42
Metal mining	0	.11	—	—
Nonmetallic minerals	.26	.14	.12	.76
Construction	9.04	4.74	4.29	26.26
Food and kindred products	1.74	1.87	—	—
Tobacco	0	.07	—	—
Textile mill production	.14	.93	—	—
Apparel and other textiles	.72	1.39	—	—
Paper and allied products	.83	.76	.08	.47
Printing and publishing	.60	1.37	—	—
Chemical and allied products	2.14	1.22	.92	5.65
Petroleum refining	.86	.22	.64	3.89
Rubber and miscellaneous plastics	.13	.80	—	—
Leather and leather products	.01	.26	—	—
Lumber and wood products, except mobile homes	.96	.71	.25	1.53
Mobile homes	.04	.05	—	—
Wood furniture	.04	.32	—	—
Other furniture and fixtures	.02	.19	—	—
Stone, clay, and glass products	.56	.73	—	—
Primary metals	.50	1.26	—	—
Fabricated metals	1.11	1.77	—	—
Machinery, excluding electrical	.82	2.73	—	—
Electrical machinery	.70	2.31	—	—
Transportation equipment, except motor vehicles	1.80	1.21	.59	3.60
Motor vehicles	.05	.87	—	—
Instruments and related equipment	.07	.77	—	—
Miscellaneous manufacturing	.09	.47	—	—
Railroad transportation	.53	.58	—	—
Trucking and warehousing	1.47	1.40	.07	.40
Local transit	.26	.29	—	—
Air transportation	.41	.50	—	—
Pipeline transportation	.07	.02	.05	.31
Transportation services	.23	.22	.01	.05
Water transportation	2.56	.23	2.33	14.27
Communications	1.49	1.48	.01	.07
Electrical, gas, and sanitation services	1.14	.90	.24	1.47
Wholesale trade	6.73	5.79	.94	5.75
Retail trade	16.78	16.50	.28	1.74
Banking	1.58	1.72	—	—

See footnotes at end of table.

Table 2—Calculation of 1980 dependency indexes for Louisiana (continued)
(In percent)

Industry	Employment		Louisiana excess employment [1]	Dependency index [2]
	Louisiana	United States		
Other credit agencies	.92	.99	—	—
Insurance	1.58	1.89	—	—
Real estate and combinations	.80	1.16	—	—
Hotel and other lodging	1.36	1.20	.16	.96
Personal, miscellaneous business, and repair services	4.86	4.69	.16	1.01
Auto repair service	.56	.63	—	—
Amusement	.60	.84	—	—
Motion pictures	.14	.24	—	—
Medical and other health	4.86	5.71	—	—
Private education	1.28	1.47	—	—
Nonprofit organizations	2.32	3.01	—	—
Miscellaneous services	1.60	1.63	—	—
Federal civilian	2.30	3.27	—	—
Federal military	2.89	2.68	.21	1.29
Nonfarm proprietors	6.98	7.66	—	—
Total [3]	100.00	100.00	16.35	100.00

[1] Louisiana employment minus U.S. employment. Figures may not be exactly equal to Louisiana minus U.S. because of rounding. Dashes signify no excess employment.

[2] Individual industry excess employment expressed as a percentage of Louisiana's total excess employment (sum of column 4).

[3] Sum of parts may not equal totals because of rounding.

Table 3—Value added, hours worked, payroll, and capital productivity, [1] Louisiana forest products industry, 1977 [2]

Industry	Value added	Payroll	Hours worked	Productivity	Productivity change, 1972-77
	- - - $Million - - -		*Million*	*$VAMP per hour*	*Percent*
Lumber and wood products	317.4	132.8	24.5	7.53	12.73
Wood furniture	12.3	5.4	1.1	6.27	−1.82
Paper and allied products	692.9	245.8	25.0	17.88	9.00

[1] Productivity equals value added minus payroll (VAMP) divided by hours worked. For a discussion of VAMP, see W. Charles Sawyer and Joseph A. Ziegler. 1980. "The use of VAMP shift as a predictive model." Unpublished paper presented at the annual meeting of the Western Regional Science Association, Monterey, California.

[2] Source: U.S. Bureau of the Census, Census of Manufactures, for 1972 and 1977, Louisiana and the United States, available in 1976 and 1980, respectively. In the few instances where data were not available for some subindustry segments, the distribution of the number of establishments was used to estimate nondisclosures.

Appendix 2, Louisiana Parishes

Code	Parish	Code	Parish
1	Acadia	33	Madison
2	Allen	34	Morehouse
3	Ascension	35	Natchitoches
4	Assumption	36	Orleans
5	Avoyelles	37	Ouachita
6	Beauregard	38	Plaquemines
7	Bienville	39	Pointe Coupee
8	Bossier	40	Rapides
9	Caddo	41	Red River
10	Calcasieu	42	Richland
11	Caldwell	43	Sabine
12	Cameron	44	St. Bernard
13	Catahoula	45	St. Charles
14	Claiborne	46	St. Helena
15	Concordia	47	St. James
16	De Soto	48	St. John the Baptist
17	East Baton Rouge	49	St. Landry
18	East Carroll	50	St. Martin
19	East Feliciana	51	St. Mary
20	Evangeline	52	St. Tammany
21	Franklin	53	Tangipahoa
22	Grant	54	Tensas
23	Iberia	55	Terrebonne
24	Iberville	56	Union
25	Jackson	57	Vermilion
26	Jefferson	58	Vernon
27	Jefferson Davis	59	Washington
28	Lafayette	60	Webster
29	Lafourche	61	West Baton Rouge
30	La Salle	62	West Carroll
31	Lincoln	63	West Feliciana
32	Livingston	64	Winn

Maki, Wilbur R.; Schallau, Con H; Foster, Bennett B.; Redmond, Clair H. Louisiana's forest products industry: performance and contribution to the State's economy, 1970 to 1980. Res. Pap. PNW-RP-371. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

Employment in Louisiana's forest products industry, unlike employment in the other 12 Southern States, decreased significantly between 1970 and 1980. Despite this decrease, the value added by the industry increased. The productivity of Louisiana's forest products industry ranked second among the 13 States in the South. In 1980, lumber and wood products accounted for the largest share of the industry's employment, but paper and allied products had a larger share of the earnings. In 1977, paper and allied products had higher productivity than either lumber and wood products or wood furniture.

Keywords: Forest products industries, employment (forest products industries), Louisiana.

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Pacific Northwest
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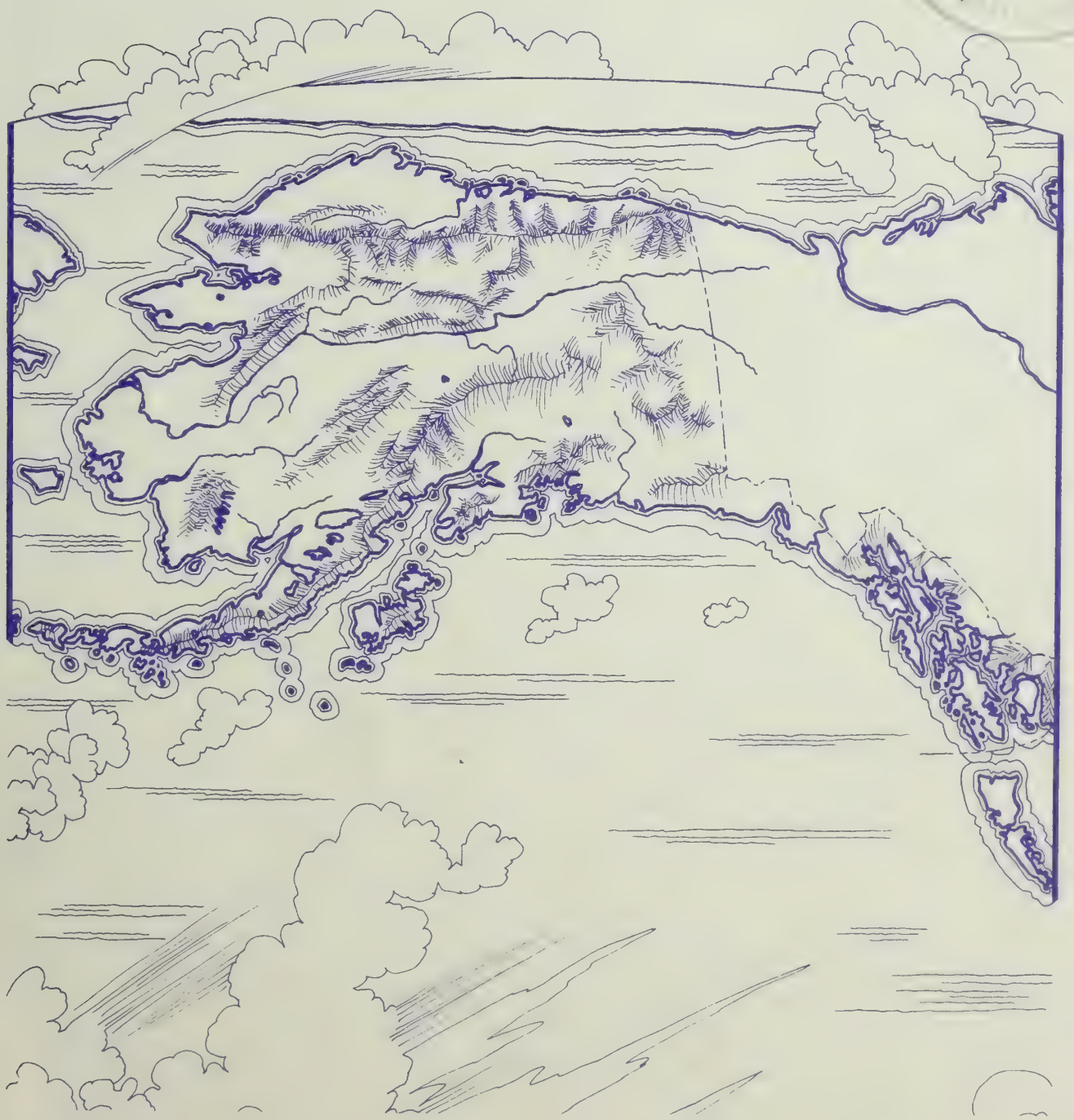
Research Paper
PNW-RP-372
January 1987

Multivariate Analysis of Climate Along the Southern Coast of Alaska — Some Forestry Implications

Wilbur A. Farr and John S. Hard



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Abstract

Farr, Wilbur A.; Hard, John S. Multivariate analysis of climate along the southern coast of Alaska--some forestry implications. Res. Pap. PNW-RP-372. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1987.** 38 p.

A multivariate analysis of climate was used to delineate 10 significantly different groups of climatic stations along the southern coast of Alaska based on latitude, longitude, seasonal temperatures and precipitation, frost-free periods, and total number of growing degree days. The climatic stations were too few to delineate this rugged, mountainous region into distinct climatic zones.

Keywords: Climate, multivariate analysis, coastal Alaska, Alaska (coastal).

Summary

Ten significantly different climatic groups were delineated along the southern coast of Alaska based on a multivariate analysis of 24 variables. The 60 climatic stations used in the analysis were too few, however, to delineate this long (2,500 miles), rugged coastal region into distinct climatic zones.

Climatic data for the period 1957-71 were used in the analysis because the greatest number of climatic stations had continuous records for that period. Principal component analysis was used to identify the significant factors that accounted for a large percentage of the total variance. Independent station scores were then used as input for a hierarchical grouping procedure. Multiple discriminate analysis was applied to test significance of the grouping procedures.

Differences in climate among most groups was not great. Changes were often gradual rather than abrupt. Only three groups were obviously different. They were (1) the treeless Aleutian Islands, (2) the transition zones between the coast and the interior, and (3) the very wet coastal stations.

Abrupt changes in vegetation do not generally occur along the coast except in the transition zones between the maritime coast and the continental interior, or along elevational transects. Species diversity is greatest in the transition zones. The relative geologic youth of the region contributes to a lack of species diversity.

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Introduction

The southern coast of Alaska is a long, narrow strip of land that forms an arc covering a coastal distance of about 2,500 miles. Latitude ranges from 52° N. in the Aleutian Islands to 61° N. in upper Cook Inlet, and longitude from 130° W. in southeast Alaska to 172° E. at the tip of the Aleutian Islands (fig. 1). This region of Alaska lies within the maritime climatic zone, a zone influenced by the Alaska Current. The Alaska Current is part of the Kuroshio Current, which flows northward from the equator (Searby 1969).

Compared to most of the vast interior of Alaska, the southern coast is cooler in summer, warmer in winter, and has more precipitation. Surface winds are moderately strong in most areas, and storm tracks pass from west to east along the coast every month of the year. From Cook Inlet east, the region is rugged and mountainous, and the lower elevations are heavily forested with western hemlock and Sitka spruce.[1/] Forests reach their western limit on Kodiak and Afognak Islands and on the nearby eastern side of the Alaska Peninsula. Wet tundra and gentler terrain characterize the naturally treeless outer Alaska Peninsula and Aleutian Islands.

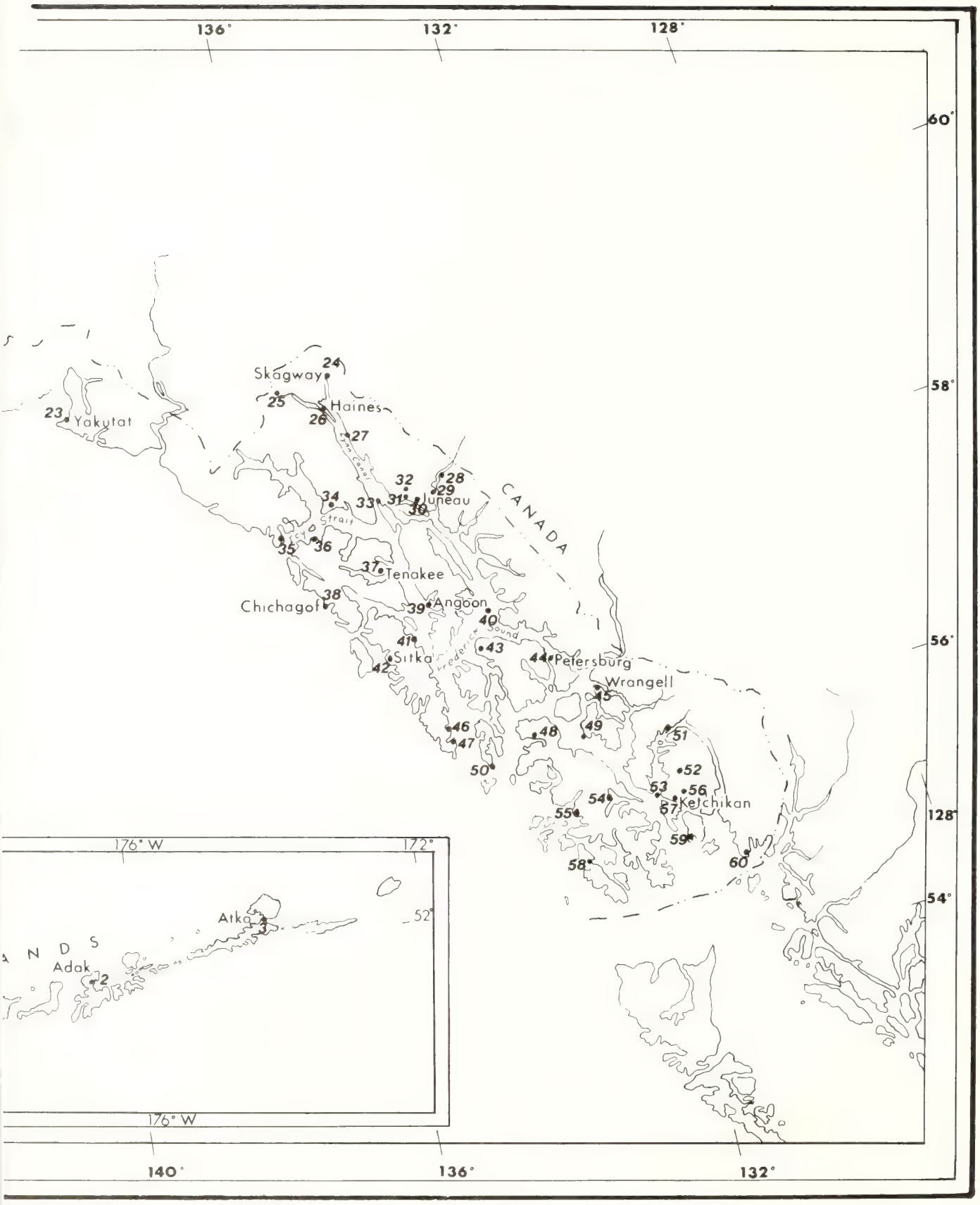
Climate along the coast seems to be relatively uniform especially near sea level, but we do know that some areas are climatically and biologically dissimilar. Tree growth, for example, diminishes with increasing latitude (Farr and Harris 1979, 1983), and distribution of plant species and plant communities differs from area to area (Hulten 1968, Viereck and Little 1972). The southern part of southeast Alaska is the northern limit of three tree species—western redcedar, Pacific yew, and Pacific silver fir—and several other plants including salal and swordfern.

Frequency and severity of major outbreaks by defoliators, such as blackheaded budworm and hemlock sawfly, also diminish with increasing latitude and decreasing temperature during the growing season (Hard 1974, 1976), and western hemlock looper has been recorded only in the southern part of southeast Alaska (Torgersen and Baker 1967). Large bark beetle outbreaks in the coastal region occur frequently only around Cook Inlet (Curtis and Swanson 1972, Werner and others 1977).

Two previous studies of climate in relation to tree growth have included climatic data from along the southern coast of Alaska. One study describes climate in southeast Alaska (Andersen 1955); the other discusses potential evapotranspiration and climate in Alaska using Thornthwaite's classification (Patric and Black 1968).

The purpose of the study reported here was to determine if discrete climatic zones or climatic station groupings could be delineated along the coast and, if so, which combinations of variables best distinguish among the zones or groups.

[1/] Scientific names for plants and insects are given in the appendix.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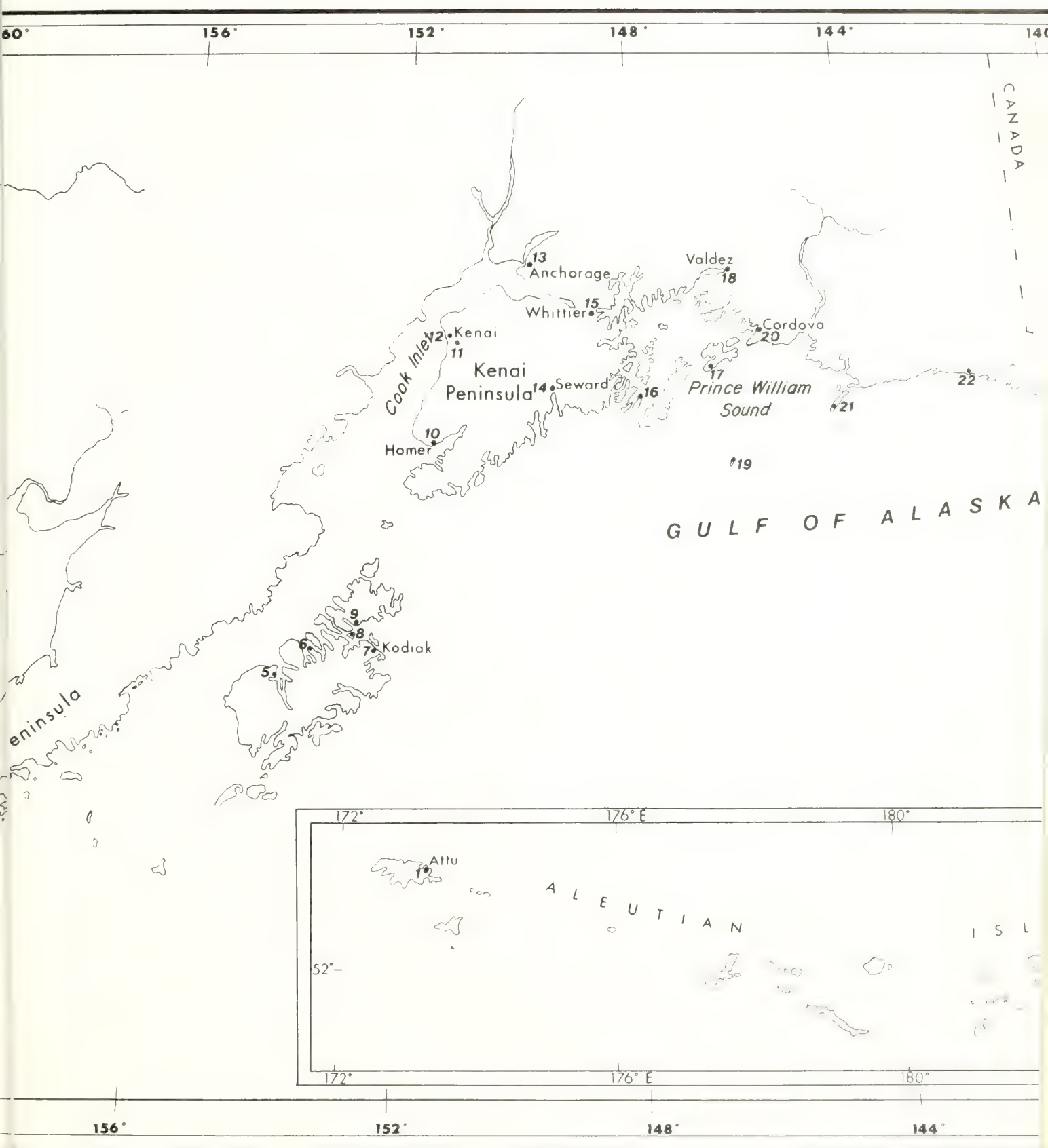
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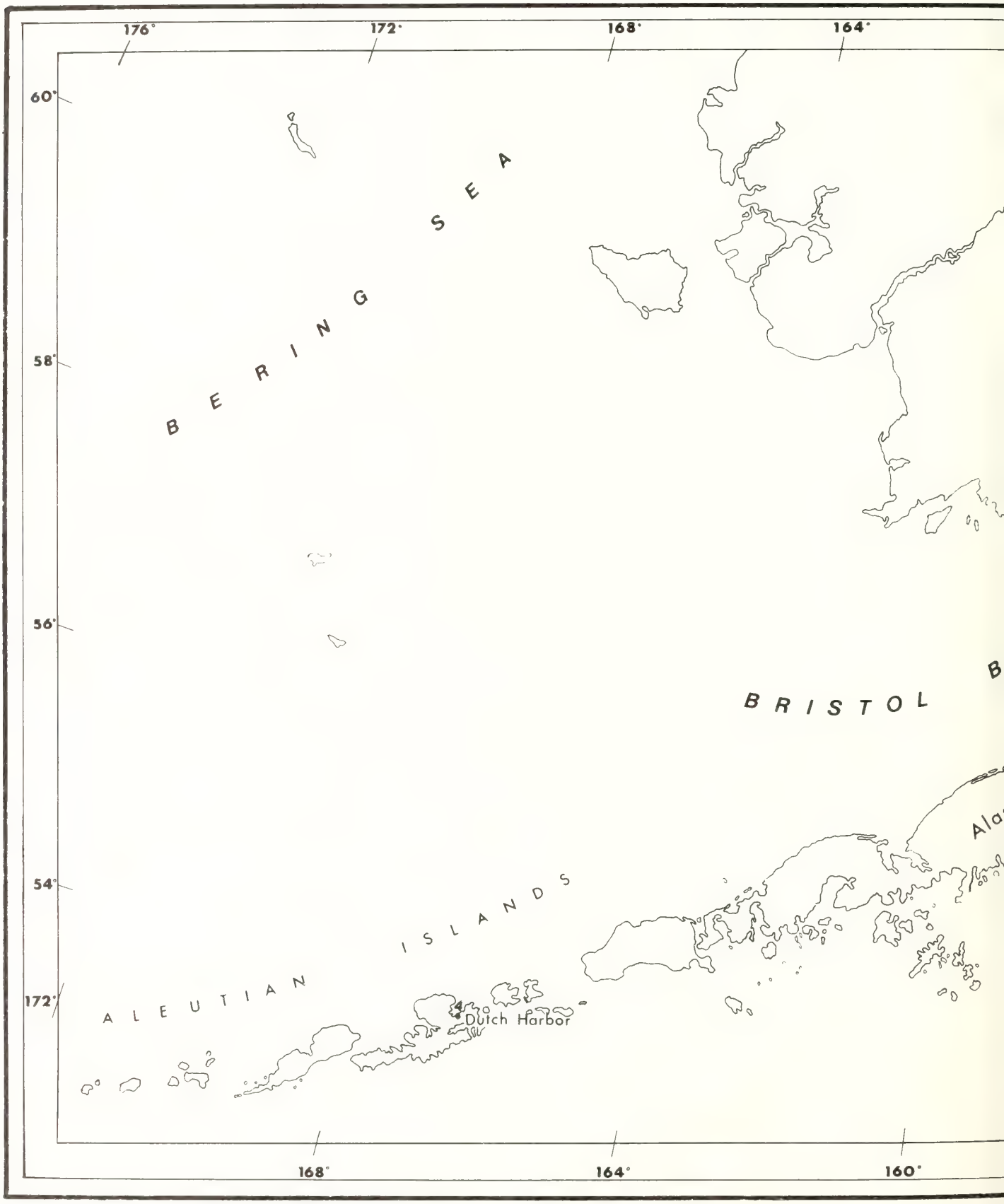

Figure 1—Locations of climatic stations along the southern coast of Alaska.

Several climatic variables and periods of record have been used to analyze climate. Commonly used variables include maximum, mininum, and mean air temperature and precipitation by month or season of the year; number and timing of frost-free periods; degree days above various threshold temperatures; and latitude, longitude, and elevation (Newnham 1968, Nicholson and Bryant 1972). Water deficiency values (Powell and MacIver 1976) and seasonal snowfall (van Groenewoud 1984) have also been used. In most studies the period of measurement has been the same for all stations and is usually 10 to 15 years in length.

Multivariate methods, including principal component analysis, factor analysis, cluster analysis, hierarchical grouping analysis, and discriminant analysis, have been used to delineate climatic zones, especially in Canada. Principal component analysis was the preferred method in some studies (Miller and Auclair 1974, Newnham 1968, Nicholson and Bryant 1972, van Groenewoud 1984, Williams and Masterton 1983) and factor analysis was used in others (MacIver and others 1972; Powell and MacIver 1976, 1977). Principal component analysis and factor analysis have much in common, but there are some important differences (Isebrands and Crow 1975, King 1969). Recently, some form of cluster analysis has been used in addition to principal component or factor analysis to statistically group climatically similar stations (van Groenewoud 1984; Powell and MacIver 1976, 1977).

This study should lead to a better general understanding of climate along the southern coast of Alaska and of climate's potential influence on biological phenomena, and will provide background for more specific studies.

Methods

Climatic data were summarized for 60 coastal stations along the southern coast of Alaska, generally for the 15-year period 1957-71 (table 1, also see appendix for individual station summaries). Some stations had shorter periods of record that occurred 40 to 50 years ago. The years between 1957 and 1971 were chosen because the greatest number of stations had continuous records for that period. Records for several of the lighthouse stations were discontinued by the mid-1970's. Only 19 of the 60 stations had continuous or nearly continuous records for the most recent 30-year reporting period, 1951-80.

Twenty-four variables were used in the analysis (table 2). Temperature, precipitation, and frost data were obtained from monthly weather summaries (U.S. Weather Bureau 1912-1980). Average seasonal temperatures and total seasonal precipitation were calculated by seasons: winter—December, January, February; spring—March, April, May; summer—June, July, August; and fall—September, October, and November. The total number of annual degree days above 41 °F. was calculated from monthly temperatures, then was adjusted upward for those days that were missed at the beginning and end of the growing season because only average monthly temperatures were used. [2/] Elevational differences could not be evaluated because all but six coastal stations are below 100 feet in elevation (table 1).

[2/] For 14 representative stations, a regression relationship was developed between degree days based on daily temperatures (Y) and degree days based on monthly temperatures (X). The equation was:

$Y = 103.40 + 1.063X$; $r^2 = 0.992$ and $Se = 42.5$.

Table 1—Climatic stations along the southern coast of Alaska that were used in the analysis

Number	Name	Period of record	Latitude N.	Longitude W.	Elevation
					Feet
1	Attu	1961-71	52°50'	1/ 173°11'	70
2	Adak	1957-71	51°53'	176°39'	15
3	Atka	1936-49	52°13'	174°12'	36
4	Dutch Harbor	1930-34	53°55'	166°30'	47
5	Larsen Bay	1957-65	57°32'	154°00'	15
6	Uganik Bay	1952-64	57°43'	153°19'	50
7	Kodiak NAS	1957-71	57°45'	152°31'	21
8	Whale Island	1924-38	57°58'	152°46'	8
9	Kitoi Bay	1957-71	58°11'	152°21'	15
10	Homer WSO	1957-71	59°38'	151°30'	67
11	Soldotna 6 W	1962-71	60°28'	151°14'	85
12	Kenai FAA AP	1957-71	60°34'	151°15'	86
13	Anchorage WSO AP	1957-71	61°10'	151°01'	114
14	Seward	1957-71	60°07'	149°27'	70
15	Whittier	1957-71	60°47'	148°41'	31
16	Latouche	1940-55	60°03'	147°54'	45
17	Cape Hinchinbrook	1957-71	60°14'	146°39'	185
18	Valdez	1957-71	61°08'	146°21'	20
19	Middleton Island	1943-58	59°28'	146°19'	39
20	Cordova	1957-71	60°30'	145°30'	41
21	Cape St. Elias	1957-71	59°48'	144°36'	58
22	Yakataga FAA	1953-67	60°05'	142°30'	27
23	Yakutat WSO AP	1957-71	59°31'	139°40'	28
24	Skagway	1922-36	59°28'	135°19'	18
25	Linger Longer	1960-71	59°26'	136°17'	700
26	Haines Terminal	1957-71	59°16'	135°27'	175
27	Eldred Rock	1957-71	58°58'	135°13'	55
28	Taku Pass	1936-44	58°33'	133°40'	175
29	Annex Creek	1937-51	58°19'	134°06'	24
30	Juneau NO 2	1957-71	58°18'	134°24'	25
31	Juneau WSO AP	1957-71	58°22'	134°35'	12
32	Juneau 9 NW	1939-43			
		1966-70	58°25'	134°32'	120
33	Point Retreat	1957-71	58°25'	134°57'	20
34	Gustavus	1956-68	58°25'	135°44'	17
35	Cape Spencer	1957-71	58°12'	136°38'	81
36	Gull Cove	1941-52	58°12'	136°09'	18
37	Tenakee	1941-50	57°47'	135°15'	19
38	Radioville	1936-50	57°36'	136°09'	15
39	Angoon	1942-52	57°30'	134°35'	35
40	Five Finger Light	1957-71	57°16'	133°37'	30
41	Baranof	1943-57	57°05'	134°50'	20
42	Sitka FAA AP	1957-71	57°04'	135°21'	15
43	Kake	1920-23			
		1930-34	56°59'	133°57'	8
44	Petersburg	1957-71	56°49'	132°57'	50
45	Wrangell	1957-71	56°28'	132°23'	37
46	Little Port Walter	1957-71	56°23'	134°39'	14
47	Port Alexander	1950-61	56°15'	134°39'	18
48	Calder	1917-31	56°10'	132°27'	20
49	Lincoln Rock	1953-67	56°03'	132°46'	25
50	Cape Decision	1957-71	56°00'	134°08'	39
51	Bell Island	1934-48	55°55'	131°35'	10
52	Fortmann Hatchery	1912-26	55°36'	131°25'	132
53	Guard Island	1957-68	55°27'	131°53'	20
54	Hollis	1954-62	55°28'	132°40'	15
55	Craig	1938-52	55°29'	133°09	13
56	Beaver Falls	1957-71	55°23'	131°28'	35
57	Ketchikan	1957-71	55°21'	131°39'	15
58	View Cove	1933-46	55°04'	133°04'	13
59	Annette Island	1957-71	55°02'	131°34'	110
60	Tree Point Light	1957-70	54°48'	130°56'	36

1/ Attu is at 173°11' E. longitude.

Table 2—Variables used in the principal component analysis

Number	Abbreviation	Name
1	LAT	Latitude
2	LONG	Longitude
		Maximum temperature (°F): 1/
3	MMATWIN	Winter
4	MMATSPR	Spring
5	MMATSUM	Summer
6	MMATFALL	Fall
		Minimum temperature (°F): 1/
7	MMITWIN	Winter
8	MMITSPR	Spring
9	MMITSUM	Summer
10	MMITFALL	Fall
		Mean temperature (°F): 1/
11	MTWIN	Winter
12	MTSPR	Spring
13	MTSUM	Summer
14	MTFALL	Fall
		Mean precipitation (inches):
15	PREWIN	Winter
16	PRESPR	Spring
17	PRESUM	Summer
18	PREFALL	Fall
19	FFREPER	Mean frost-free period (days)
20	FFRFALL	Mean date first fall frost 2/
21	LAFRSPR	Latest spring frost 2/
22	EAFRFALL	Earliest fall frost 2/
23	SHFRFRPE	Shortest frost-free period (days)
24	DEGREE	Degree days above 41 °F

1/ Mean daily temperature by season: winter--December, January, February; spring--March, April, May; summer--June, July, August; fall--September, October, November.

2/ Days since January 1.

Principal component analysis was used to identify the significant factors that accounted for a large percentage of the total variance. Principal component analysis produced correlation matrices and their associated eigenvalues and eigenvectors. Eigenvector coefficients multiplied by the input variables for each station were summed to derive weighted station scores for each station.

The independent station scores were used as input for a hierarchical grouping procedure (Powell and MacIver 1976, 1977; Veldman 1967) that, through stepping, groups stations by minimizing the increment of within-group station score variation. In the first step each station is placed in a separate group. The procedure then groups stations, one entry at a time, until all stations are in one group. At each step, the output lists the stations in each group and the aggregate within-group error. The relation between aggregate error and number of groups was used to look for inflection points where large increases occurred in the error between steps.

When a minimum number of groups was selected, multiple discriminate analysis was applied to test significance of the grouping procedures and to identify the major discriminating variables (Mather 1969, Powell and MacIver 1977).

Results and Discussion

Several computer runs using data from various combinations of stations produced similar results. In the final analysis all stations were used, although not all had similar periods of record. The results presented here must be considered first approximations because (1) relatively few data have been collected along the coast, (2) all stations do not have the same period of record, and (3) most data came from stations at or near sea level and immediately adjacent to salt water.

The matrix of correlation coefficients showed that many of the original 24 variables were highly correlated, which made a direct interpretation of them very difficult. The principal component analysis performed on this matrix revealed that five components (eigenvectors), each with eigenvalues greater than 1.00, accounted for 91 percent of the observed variation in climate (table 3). In descending order, the components explain 52, 18, 11, 6, and 4 percent of the observed variation among stations.

The first component is characterized by high positive coefficients for fall, winter, and spring temperatures, length of growing season, and date of first fall frost, and a high negative coefficient for latitude. The second component is characterized by high positive coefficients for mean maximum spring and summer temperatures, mean summer temperature, and total degree days, and a high negative coefficient for longitude.

The third component has high positive coefficients for precipitation during all four seasons. The fourth component is a measure of the latest spring frost, and the fifth component is a measure of the earliest fall frost.

The components were independent, and the sorting of cold-season and warm-season variables into different components demonstrated independence of conditions in the two seasons. Stations warmer in summer were not necessarily warmer in winter.

Weighted station scores, computed from the eigenvector coefficients and input variables, were plotted for the first three components (fig. 2). The distribution of stations in figure 2 shows few distinct groupings in two-dimensional space. Most stations appear grouped in one cluster. A test of possible station groupings was next performed using hierarchical grouping analysis.

Computed weighted station scores were used as input to the hierarchical grouping procedure (Powell and MacIver 1976, 1977; Veldman 1967). Raw data were also used in a separate run. Both gave similar results. The hierarchical procedure groups stations in a stepwise fashion beginning with 60 one-station groups and ending with one 60-station group. A listing of stations in each group and total within-group error are printed following each step. The increase in within-group error was then used to identify points in the process where sharp increases appeared in the within-group error.

Table 3—Climatic variables and the first 5 eigenvalues and eigenvectors from the principal component analysis [1/]

Variable		Component (eigenvector)				
Number	Abbreviation	1	2	3	4	5
1	LAT	-0.731	0.072	-0.005	0.190	-0.446
2	LONG	-.128	-.829	-.232	-.109	.212
3	MATWIN	.921	.069	.234	.038	.164
4	MATSPR	.308	.884	.123	-.077	.124
5	MATSUM	-.259	.930	-.008	-.109	.110
6	MATFALL	.779	.472	.211	-.052	.194
7	MITWIN	.936	-.034	.222	.202	.060
8	MITSPR	.861	.238	.137	.364	-.034
9	MITSUM	.432	.550	.070	.557	-.122
10	MITFALL	.916	.143	.213	.263	.030
11	MTWIN	.945	.001	.231	.142	.089
12	MTSPR	.706	.624	.146	.189	.042
13	MTSUM	-.003	.948	.019	.191	.027
14	MTFALL	.911	.278	.208	.147	.085
15	PREWIN	.289	.157	.901	.059	.177
16	PRESPR	.233	.064	.938	.079	.147
17	PRESUM	.115	.010	.910	.207	-.097
18	PREFALL	.242	.201	.918	.124	.096
19	FFREPER	.705	.084	.146	.632	.103
20	FFRFALL	.756	.013	.146	.524	.187
21	LAFRSPR	-.098	-.061	-.173	-.748	-.058
22	EAFRFALL	.294	.068	.220	.225	.808
23	SHFRFRPE	.459	.216	.241	.627	.425
24	DEGREE	.298	.907	.078	.212	.086
Eigenvalues		8.709	5.268	3.952	2.527	1.353
Percent variation accounted for		52.05	17.29	11.17	6.19	4.18
Cumulative percent		52.04	69.33	80.51	86.70	90.88

1/ Variables contributing the most variation to each principal component are underlined.

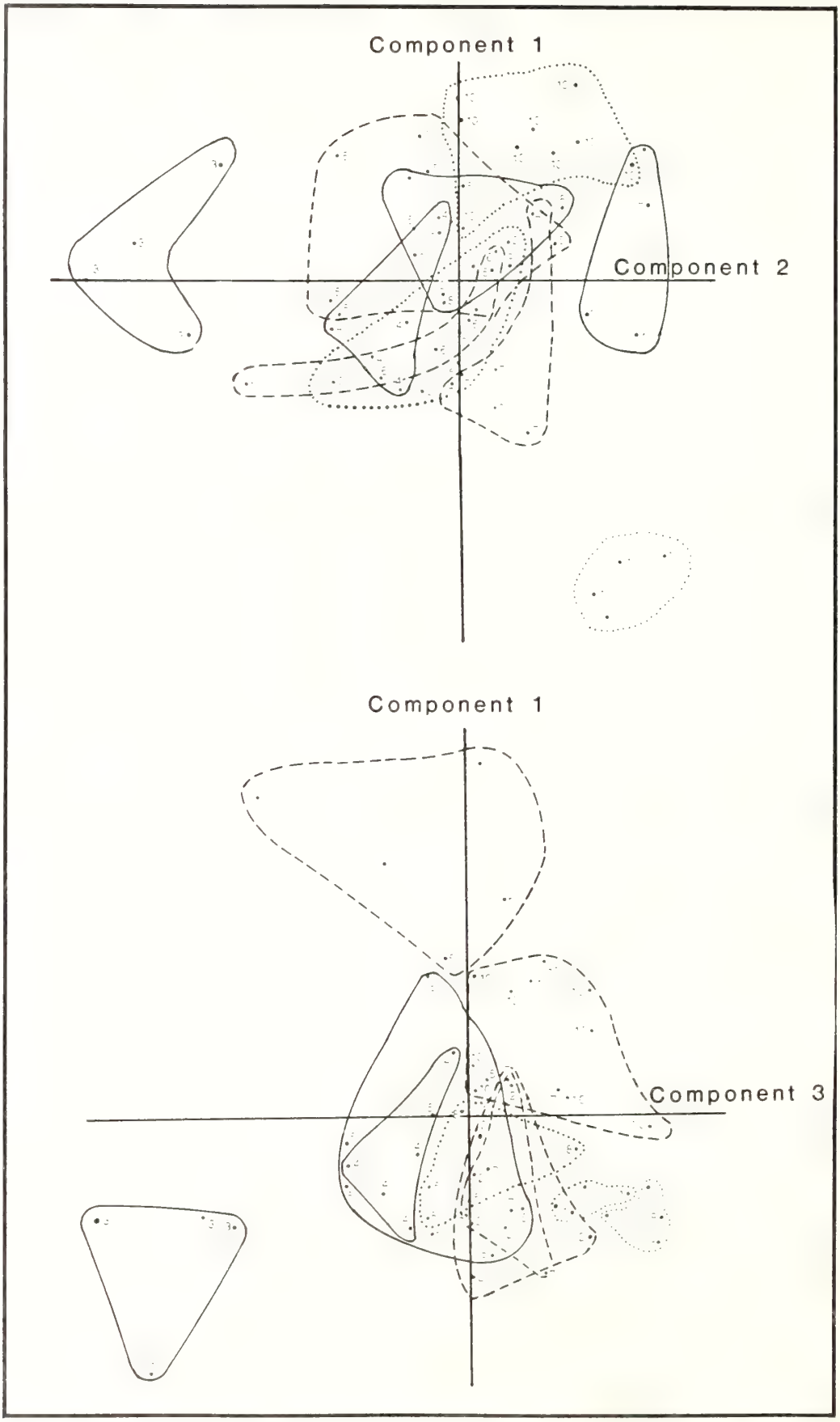

Figure 2—Weighted station scores plotted for the first three components. Groups of similar stations are indicated by group number and are encircled by lines. Stations in each group are given in table 4

The hierarchical procedure indicated that the optimum number of groups was either 10 or 7. Ten was selected because the within-group error is more than 100 percent higher with 7 groups. The 10 groupings are delineated in figure 2 and listed in table 4.

Multiple discriminant analysis showed that the 10 groups of stations are separate and are mutually exclusive, and that individual stations were correctly placed in their respective group.

Table 4—Climatic stations along the southern coast of Alaska by climatic group

Group	Station number	Station name	Group	Station number	Station name
1	1	Attu	6	15	Whittier
	2	Adak		16	Latouche
	3	Atka		41	Baranof
	4	Dutch Harbor		46	Little Port Walter
				47	Port Alexander
2	5	Larsen Bay			
	6	Uganik Bay	7	17	Cape Hinchinbrook
	7	Kodiak NAS		19	Middleton Island
	8	Whale Island		21	Cape St. Elias
	9	Kitoi Bay		35	Cape Spencer
	10	Homer WSO		38	Radioville
3	11	Soldotna 6 W	8	26	Haines Terminal
	12	Kenai FAA AP		29	Annex Creek
	13	Anchorage WSO AP		45	Wrangell
	25	Linger Longer			
			9	40	Five Finger Light
4	20	Cordova		49	Lincoln Rock
	22	Yakataga FAA		50	Cape Decision
	23	Yakutat WSO AP		53	Guard Island
	32	Juneau 9 NW			
	34	Gustavus	10	44	Petersburg
				48	Calder
5	14	Seward		51	Bell Island
	18	Valdez		52	Fortmann Hatchery
	24	Skagway		54	Hollis
	27	Eldred Rock		55	Craig
	28	Taku Pass		56	Beaver Falls
	30	Juneau NO 2		57	Ketchikan
	31	Juneau WSO AP		58	View Cove
	33	Point Retreat		59	Annette Island
	36	Gull Cove		60	Tree Point Light
	37	Tenakee			
	39	Angoon			
	42	Sitka FAA AP			
	43	Kake			

Most groups shown in two-dimensional planes in figure 2 overlap, which suggests similarity among stations in the region. This was expected. Exceptions were group 1 (Aleutian Islands), group 3 (Cook Inlet and one station at the head of Lynn Canal in southeast Alaska), group 6 (scattered but very wet coastal stations), group 9 (four lighthouse stations in southeast Alaska), and group 10 (stations in southernmost part of southeast Alaska). Groups 1, 3, and 6 are extremes.

Stations in group 1 (1, 2, 3, and 4) are in the Aleutian Islands, an area with moderately cool temperatures in the fall, winter, and spring, and much colder summers than other coastal stations. The Aleutians are naturally treeless except where planted (Bruce and Court 1945, Lutz 1963). Faunal diversity is also limited, and the naturally occurring mammalian complex there is composed largely of rodents and marine mammals.

Three stations in group 3 (11, 12, and 13) are along Cook Inlet, and station 25 is 40 miles inland from the head of Lynn Canal. These stations are in a transition zone between the maritime climate of the coast and the dryer continental climate of the interior. They are warm in the summer and cold the rest of the year and have much less precipitation than other coastal stations. Botanical diversity is rich in these transition areas. More species of plants occur around Cook Inlet and Lynn Canal than in other geographic areas along the southern coast of Alaska. White spruce, black spruce, paper birch, aspen, and balsam poplar (typical interior species) reach the coast at Cook Inlet. Lutz spruce, a natural hybrid of white spruce and Sitka spruce, occur extensively around upper Cook Inlet and in the transition area along the Skeena River of coastal British Columbia (Daubenmire 1968). It has also been reported near the international border north of Haines (von Rudloff 1977). Paper birch, aspen, and balsam poplar also reach the coast at the head of Lynn Canal, along with interior form lodgepole pine.

Spruce beetle epidemics are chronic in stands along Cook inlet and occur regularly only in that area of the coast, but a large outbreak occurred north of Haines near the border with Canada in the 1940's, and a current outbreak is located near Gustavus in southeast Alaska. The only known spruce budworm outbreak in southern coastal Alaska occurred in Sitka spruce near Haines, Alaska, in the late 1940's and early 1950's (Downing 1975).

The stations in group 6 all have very high annual precipitation, in excess of 180 inches a year.

Station groupings (table 4) suggest that it is not practical to divide the southern coast of Alaska into distinct climatic zones because stations within the same group are sometimes located in widely separated geographic areas. The region covers a long, narrow, rugged, mountainous strip of land cut by numerous waterways that originate in much dryer areas of interior Alaska and Canada. There are relatively few climatic stations; all are located at or near sea level and have varying periods of record. Temperature and precipitation also fluctuate markedly over short distances (Andersen 1955, Farr and others 1977), and several of the stations are located on islets. Temperatures at these small islands and at other exposed lighthouse stations are greatly influenced by the surrounding water.

Although it may not be practical to delineate distinct climatic zones similar to those prepared for Provinces in Canada (Newnham 1968; Nicholson and Bryant 1972; Powell and MacIver 1976, 1977; Williams and Masterton 1983; van Groenewoud 1984), there are distinct groups of stations that can be described. Means, minimums, and maximums for variables describing these groups of stations are summarized in table 5.

Table 5—Mean, minimum, and maximum for the 24 variables used in the analysis for each of the 10 station groups

Group	Range of values	Latitude N.	Longitude W.	Mean maximum temp.				Mean minimum temp.				Mean temp.				Mean precipitation				Mean frost-free period	First fall frost	Latest spring frost	Earliest fall frost	Shortest frost-free period	Annual degree days
				Win.	Spr.	Sum.	Fall	Win.	Spr.	Sum.	Fall	Win.	Spr.	Sum.	Fall	Win.	Spr.	Sum.	Fall						
				°F 1/												Inches 2/				Days 3/					
1	Mean	52°41'	172°38'	36.6	41.2	53.2	46.8	28.9	32.6	44.2	38.2	32.7	37.0	48.7	42.4	5.8	4.5	3.3	6.3	161	292	151	259	117	1140
	Min	51°53'	166°32'	34.5	38.6	51.1	45.7	28.1	32.0	43.8	37.6	31.1	35.5	47.5	41.5	4.5	3.6	2.3	4.5	158	284	140	225	100	979
	Max	53°53	176°11'E.	37.9	42.5	56.0	47.4	30.0	33.6	44.9	38.5	33.7	38.1	50.5	42.9	6.9	5.4	4.0	7.7	165	300	166	284	139	1351
2	Mean	58°08'	152°43'	34.2	43.5	59.7	46.7	22.8	30.0	45.6	34.2	28.5	36.7	52.7	40.5	3.9	2.9	3.0	4.8	125	270	168	253	96	1566
	Min	59°32'	151 30'	29.2	42.5	58.1	44.5	16.7	27.4	43.9	30.7	22.9	35.0	51.6	37.6	2.0	1.2	1.5	2.9	107	258	153	243	78	1397
	Max	59°38'	154°00'	36.3	45.3	63.2	48.0	26.2	32.4	47.6	36.8	30.7	37.6	54.2	41.8	5.5	4.4	4.6	6.2	154	279	178	260	119	1749
3	Mean	60°31'	147°09'	23.1	44.0	63.8	42.6	6.2	24.7	45.6	26.4	14.6	34.4	54.7	34.5	1.7	1.1	1.8	2.6	111	256	156	240	88	1782
	Min	59°26'	136°17'	22.4	42.4	60.6	41.2	.7	21.0	43.5	21.2	11.6	32.5	52.8	31.9	.9	.6	1.3	1.6	94	245	142	232	69	1540
	Max	61°10'	151°15'	24.3	47.0	67.5	43.7	10.5	27.4	49.4	30.1	17.4	36.8	56.3	37.0	3.1	1.9	2.1	4.9	135	266	161	249	115	2006
4	Mean	59°20'	139°35'	33.3	45.4	59.1	46.8	20.1	30.2	45.6	34.4	26.7	37.8	52.4	40.6	7.3	5.4	6.7	11.4	120	261	153	238	89	1583
	Min	58°24'	134°33'	32.5	43.4	56.6	46.2	16.9	28.3	43.5	32.2	24.8	36.1	51.0	39.4	4.4	2.4	4.1	7.2	110	254	116	221	64	1447
	Max	60°18'	145°30'	34.6	48.1	62.1	47.8	24.0	31.7	47.3	36.3	29.3	39.9	54.7	42.1	11.5	9.0	8.9	16.2	141	275	172	264	115	1960
5	Mean	58°32'	136°50'	32.9	46.9	62.0	47.4	23.2	33.2	47.3	36.5	28.0	40.0	54.6	42.0	5.2	3.6	3.8	8.3	153	281	149	252	119	1998
	Min	56°59'	133°41'	27.1	44.4	59.5	44.0	13.2	27.9	44.8	29.8	20.5	36.6	52.9	36.9	2.6	1.5	1.5	4.4	111	258	133	236	79	1611
	Max	61°07'	149°27'	39.3	50.1	66.4	50.5	31.1	36.4	50.5	41.4	35.2	42.2	56.6	46.0	8.9	6.0	6.4	13.9	191	304	176	276	151	2344
6	Mean	58°07'	140°08'	34.8	44.7	59.6	47.1	26.6	32.7	47.0	37.7	30.6	38.8	53.2	42.4	16.8	12.5	9.2	21.0	163	289	150	266	128	1768
	Min	56°15'	134°39'	30.8	42.0	58.2	43.2	21.4	30.1	46.3	33.1	26.1	36.1	51.5	38.2	14.1	10.0	4.7	18.2	144	275	140	252	118	1624
	Max	60°47'	148°41'	37.5	47.0	62.0	49.3	30.4	35.8	47.5	40.1	33.9	41.4	54.5	44.8	22.4	14.2	12.3	28.1	175	299	158	279	150	2058
7	Mean	59°04'	142°04'	36.2	44.5	57.3	48.2	30.0	35.5	48.4	40.5	33.4	40.0	52.8	44.4	7.8	6.0	6.7	11.9	194	304	135	254	133	1841
	Min	57°36'	136°09'	34.1	42.3	55.2	46.6	28.7	34.1	47.7	39.6	32.0	38.2	51.5	43.1	5.0	3.4	3.5	7.4	177	292	125	198	89	1628
	Max	60°14'	146°39'	38.8	50.6	61.5	51.7	31.0	36.9	49.2	41.3	34.4	43.6	54.8	46.4	8.9	7.0	8.4	15.2	212	316	157	278	166	2355
8	Mean	58°01'	133°59'	32.0	47.2	62.5	47.0	22.2	33.5	47.3	36.1	27.2	40.4	54.9	41.6	6.7	4.9	5.1	11.1	157	280	141	230	128	1978
	Min	56°28'	132°23'	29.2	45.5	61.4	45.0	20.7	32.2	46.5	35.3	25.1	39.7	54.0	40.5	5.2	3.0	2.0	6.9	148	272	138	179	118	1828
	Max	59°16'	135°27'	35.5	48.5	63.6	49.0	25.1	34.3	48.8	36.9	30.3	41.5	56.2	43.0	8.1	6.5	8.2	16.3	169	290	145	271	141	2103
9	Mean	56°11'	132°58'	39.1	47.3	59.6	49.6	31.6	37.6	49.7	42.0	35.4	42.4	54.6	45.8	6.1	3.9	3.8	8.0	192	303	161	242	120	2218
	Min	55°27'	131°53'	37.1	46.3	56.0	48.0	29.7	36.7	48.1	40.4	33.5	41.5	52.1	44.2	5.1	3.0	3.5	7.1	187	299	149	236	105	1888
	Max	57°16'	134°08'	40.1	48.9	62.6	50.7	33.4	38.5	52.1	43.6	36.7	43.7	57.4	47.2	7.1	4.5	4.1	8.6	198	308	182	251	140	2695
10	Mean	55°34'	132°05'	38.6	49.8	64.0	51.5	28.6	35.0	48.8	40.2	33.5	42.4	56.3	45.6	12.1	8.3	6.1	15.3	172	292	148	270	138	2446
	Min	54°48'	130°56'	34.7	47.6	61.2	48.3	24.5	32.1	45.9	37.0	29.0	39.9	53.6	42.7	9.5	6.4	3.9	12.4	126	270	133	251	106	1907
	Max	56°49'	133°09'	42.1	51.5	67.5	54.7	32.0	37.6	50.8	42.5	36.9	44.2	58.0	48.6	17.4	11.1	9.2	19.2	208	308	167	294	173	2725

1/ Per day.
2/ Per month.
3/ Days since January 1.

Stations in group 1, located in the naturally treeless Aleutian Islands, have much cooler summers and a much lower total number of degree days than do other coastal stations. They are also easily separated by their geographic location.

Group 2 includes the stations on and around Kodiak Island and those at nearby Homer on the Kenai Peninsula. These stations have warmer summers than the Aleutians but are cooler in the fall and winter.

Stations in group 3 are located around Cook Inlet and at the head of Lynn Canal in southeast Alaska in a transition zone between the moist maritime climate of the coast and the continental climate of the interior. Cold winter temperatures and relatively low precipitation throughout the year characterize these stations.

Stations in group 4 are mostly along the Gulf of Alaska, but also include Juneau 9 NW and Gustavus in the northern part of southeast Alaska. These stations have climates similar to those in group 2 except that they have significantly more precipitation throughout the year.

Group 5 includes 13 stations that cover a wide range of longitude. They form a center group of stations with values close to the mean for all variables. Although there appear to be differences between some of these stations, the differences are not sufficiently large to place them in one of the other nine groups or to form a separate group. They are warmer in spring, summer, and fall than stations in groups 1, 2, or 4.

Stations in group 6 have much more winter rainfall than do other stations. Little Port Walter located on the southern end of Baranof Island in southeast Alaska, for example, has an average monthly rainfall of 21 inches during the winter. Mean monthly precipitation during fall averages 29 inches.

Group 7 includes four northernmost lighthouse stations in southeast Alaska and Radioville on Chicagof Island. These stations have higher maximum and minimum fall temperatures and a longer frost-free period than other nearby stations because of the influence of surrounding salt water.

The three stations in group 8 are similar to those in groups 5 and 9 except that they have cooler winter temperatures.

Group 9 includes four lighthouse stations in the southernmost part of southeast Alaska. Fall and winter temperatures at these stations are moderated by the surrounding salt water; the mean date of the first fall frost is later in the year than for most other stations.

Group 10 includes 10 stations in the southern part of southeast Alaska that have relatively mild fall and winter temperatures and abundant precipitation during the winter. This group encompasses the area where outbreaks of hemlock sawfly, a major defoliator of western hemlock, commonly occur, and where the only known western hemlock looper outbreak in Alaska occurred.

Differences in climate among most groups are not great. Differences may be reflected in mean or maximum temperatures during the fall or winter, length or initiation of the frost-free period, or the abundance of precipitation. Changes are often gradual rather than abrupt.

Abrupt changes in vegetation due to abrupt changes in climate do not generally occur along the coast except in the transition zones between the maritime coast and the continental interior, or along elevational transects that could not be evaluated in this study because all stations are located at or near sea level.

An analysis of occurrence of species of plants along the southern coast of Alaska shows that species diversity is greatest in the transition zones between the maritime climate of the coast and the continental climate of the interior of Alaska (Hulten 1968) (table 6). Otherwise, species diversity decreases with increasing latitude through southeast Alaska and along the Gulf of Alaska. Western redcedar, Pacific yew, and Pacific silver fir reach the northern limit of their ranges in the southern part of southeast Alaska, although climate does not appear to limit their northern ranges. More likely these species are still expanding their ranges following Pleistocene deglaciation (Heusser 1960). Western redcedar and Pacific silver fir both reach large size at their northern limits in southeast Alaska. For example, Pacific silver fir 4 feet in diameter and 150 feet tall have been reported (Harris and Farr 1974). Salal, swordfern, and other species may also be expanding their ranges northward. Information on frequency of seed crops, seed dispersal distances, and requirements for germination for these and other species common to coastal Alaska are generally lacking.

Mountain hemlock is found at upper elevations on productive forest land in southeast Alaska and at sea level along Prince William Sound. The elevational limit of western hemlock decreases with latitude and reaches its western limit along western Prince William Sound. Sitka spruce continues to expand its range westward on Kodiak and Afognak Islands (Griggs 1934, 1946). In southeast Alaska, timberline is at 2,500 to 3,500 feet in elevation; in western Prince William Sound, timberline is at 500 to 1,000 feet.

The relative geologic youth of the region also contributes to a lack of species diversity. Southeast Alaska was covered with glaciers 10,000 years ago, and active glacier recession and isostatic rebound are still in evidence today (Heusser 1960). Species migrations into or through the region from Ice Age refugia have apparently occurred over a relatively short time.

Table 6—Number of plant species[1/] by geographic area[2/]

Type of plants	Geographic area								
	1	2	3	4	5	6	7	8	Total
Trees	12	8	15	9	11	14	5	0	22
Shrubs	56	53	82	36	56	75	55	36	107
Herbs	263	282	467	198	275	356	348	275	717
Ferns	18	20	23	10	19	15	11	14	32
Grasses	127	126	206	72	152	197	146	143	321
Mosses and clubmosses	10	8	11	4	7	8	7	10	15
Total	486	497	804	329	520	665	572	478	1214

1/ Summarized from Hulten 1968.

2/ Geographic areas:
1. Southeast Alaska south of Frederick Sound.
2. Southeast Alaska north of Frederick Sound to Icy Bay.
3. Lynn Canal and Icy Strait.
4. Gulf coast from Icy Bay to Prince William Sound.
5. Prince William Sound and eastern Kenai Peninsula.
6. Cook Inlet.
7. Kodiak-Afognak Islands and Alaska Peninsula.
8. Aleutian Islands.

Conclusions

Based on an exploratory multivariate analysis of climate for 60 coastal stations along the southern coast of Alaska, it was possible to delineate 10 significantly different groups of stations based on latitude, longitude, seasonal mean and maximum temperatures, seasonal precipitation, frost-free periods, and total number of degree days. Because of the rugged, mountainous terrain, relatively few climatic stations, and varying periods of record, the entire coastal region cannot be delineated into tentative climatic zones, although three zones were obviously different from the remaining areas. The treeless Aleutian Islands (group 1), the transition zones between the coast and interior (group 3), and the very wet coastal stations (group 6) could easily be mapped as climatically distinct, but much more information is needed before a useful map of climatic zones can be delineated for the south coastal region. An independent test would also be needed to support such conclusions.

Metric Equivalents

1 mile = 1.61 kilometers
1 foot = 0.31 meter
1 inch = 2.54 centimeters
1 °F = (9/5 °C) + 32

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Appendix

Common and Scientific Names

Plants

Quaking aspen, *Populus tremuloides* Michx.
Paper birch, *Betula papyrifera* Marsh.
Pacific silver fir, *Abies amabilis* Dougl. ex Forbes
Mountain hemlock, *Tsuga mertensiana* (Bong.) Carr.
Western hemlock, *Tsuga heterophylla* (Raf.) Sarg.
Lodgepole pine, *Pinus contorta* var. *latifolia* Engelm.
Balsam poplar, *Populus balsamifera* L.
Western redcedar, *Thuja plicata* Donn ex D. Don
Salal, *Gaultheria shallon* Pursh
Lutz spruce, *Picea* x *lutzii* Little
Black spruce, *Picea mariana* (Mill.) B.S.P.
Sitka spruce, *Picea sitchensis* (Bong.) Carr.
White spruce, *Picea glauca* (Moench) Voss
Swordfern, *Polystichum munitum* (Kaulf.) Presl
Pacific yew, *Taxus brevifolia* Nutt.

Insects

Spruce beetle, *Dendroctonus rufipennis* (Kirby)
Blackheaded budworm, *Acleris gloverana* (Wals.)
Spruce budworm, *Choristoneura sp.*
Western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst)
Hemlock sawfly, *Neodiprion tsugae* Midd.

Station Summaries

ADAK: 2

Period: 1957-71 | Mean annual degree days above 41 °F: 1,136 | Mean frost-free period: 159 days

Latitude: 51° 53' N. | Longitude: 176° 39' W. | Elevation: 15 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	38.3	37.2	39.4	42.2	45.9	49.1	54.0	55.9	52.5	47.0	41.7	38.2	45.1
Minimum	29.4	28.2	30.6	33.3	37.0	40.7	44.5	46.7	43.7	38.4	33.0	30.0	36.3
Average	33.8	32.7	35.0	37.8	41.4	44.9	49.2	51.3	48.1	42.7	37.4	34.1	40.7
						Inches							
Precipitation	6.33	4.55	5.69	4.95	3.34	2.29	2.88	3.58	5.54	6.51	7.52	7.23	60.41

ANCHORAGE WSO AP: 13

Period: 1957-71 | Mean annual degree days above 41 °F: 2,006 | Mean frost-free period: 135 days

Latitude: 61° 10' N. | Longitude: 150° 01' W. | Elevation: 114 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	19.3	26.5	31.6	42.8	54.6	62.3	64.6	62.9	54.9	40.7	28.0	21.3	42.4
Minimum	5.2	11.8	15.4	28.6	38.1	47.5	51.0	49.7	41.0	27.7	15.6	8.0	28.3
Average	12.3	19.2	23.5	35.7	46.4	54.9	57.8	56.3	48.0	34.2	21.8	14.6	35.4
						Inches							
Precipitation	.85	.85	.57	.63	.74	1.07	2.22	2.08	2.25	1.34	1.11	1.08	14.79

ANGOON: 39

Period: 1942-52 | Mean annual degree days above 41 °F: 1,921 | Mean frost-free period: 165 days

Latitude: 57° 30' N. | Longitude: 134° 35' W. | Elevation: 35 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	32.4	34.7	40.0	45.3	52.3	58.9	60.8	60.4	55.8	47.5	39.1	34.1	46.8
Minimum	23.7	25.8	29.3	34.0	39.7	44.7	48.0	49.1	44.6	38.3	30.7	26.4	36.2
Average	28.0	30.2	34.6	39.6	46.0	51.8	54.4	54.8	50.2	42.9	34.9	30.2	41.6
						Inches							
Precipitation	3.91	1.85	2.33	2.19	1.65	1.40	3.22	3.31	5.73	6.77	4.26	2.28	38.90

ANNETTE WSO AP: 59

Period: 1957-71 | Mean annual degree days above 41 °F: 2,718 | Mean frost-free period: 205 days

Latitude: 55° 02' N. | Longitude: 131° 34' W. | Elevation: 110 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	38.0	42.8	44.6	50.0	56.8	62.1	65.5	64.8	60.4	52.5	44.3	40.0	51.8
Minimum	28.7	32.7	33.4	37.0	42.3	48.2	52.1	52.0	48.3	42.3	35.4	31.3	40.3
Average	33.4	37.8	39.0	43.5	49.6	55.2	58.8	58.4	54.4	47.4	39.9	35.7	46.1
						Inches							
Precipitation	12.18	10.45	9.52	9.15	6.65	4.76	5.39	7.79	10.49	19.20	14.12	13.63	123.23

ANNEX CREEK: 29

Period: 1937-51 | Mean annual degree days above 41 °F: 1,828 | Mean frost-free period: 155 days

Latitude: 58° 19' N. | Longitude: 134° 06' W. | Elevation: 24 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	29.5	29.2	37.9	44.8	53.9	61.8	62.3	60.0	54.2	45.8	35.0	28.9	45.3
Minimum	20.4	21.0	28.2	33.9	39.5	45.5	47.7	46.3	43.6	37.2	27.1	21.3	34.4
Average	25.0	25.1	33.1	39.4	46.7	53.7	55.0	53.2	48.9	41.5	31.1	25.1	39.8
						Inches							
Precipitation	8.70	6.18	6.53	6.06	6.76	5.87	7.76	11.03	16.47	19.23	13.32	9.56	117.47

ATKA: 3

Period: 1936-49 | Mean annual degree days above 41 °F: 1,093 | Mean frost-free period: 165 days

Latitude: 52° 13' N. | Longitude: 174° 12' W. | Elevation: 36 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	37.2	37.9	38.8	42.1	45.2	48.8	52.9	56.8	52.8	46.5	41.7	37.0	44.8
Minimum	30.3	30.2	29.5	32.4	35.7	40.6	44.3	47.0	43.9	37.1	33.4	29.4	36.2
Average	33.8	34.1	34.2	37.3	40.5	44.7	48.6	51.9	48.4	41.8	37.6	33.2	40.5
						Inches							
Precipitation	5.21	5.29	4.82	4.19	4.22	3.03	4.17	4.49	7.86	6.42	8.76	6.22	64.68

ATTU: 1

Period: 1961-71 | Mean annual degree days above 41 °F: 979 | Mean frost-free period: 162 days

Latitude: 52° 50' N. | Longitude: 173° 11' E. | Elevation: 70 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	34.7	33.1	35.2	38.0	42.7	47.6	51.5	54.3	52.3	45.6	39.1	35.6	42.5
Minimum	28.6	26.7	29.0	31.8	36.4	40.6	44.5	46.3	44.0	37.0	31.9	29.1	35.5
Average	31.7	29.9	32.1	34.9	39.6	44.1	48.0	50.3	48.2	41.3	35.5	32.4	39.0
						Inches							
Precipitation	3.58	4.83	3.83	3.93	2.96	2.63	4.53	4.92	4.95	4.44	4.18	5.00	49.78

BARANOF: 41

Period: 1943-57 | Mean annual degree days above 41 °F: 1,631 | Mean frost-free period: 155 days

Latitude: 57° 05' N. | Longitude: 134° 50' W. | Elevation: 20 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	31.9	34.3	39.1	44.2	52.1	54.0	60.4	60.2	55.2	47.3	40.2	35.2	46.2
Minimum	22.5	24.2	25.6	30.8	35.8	43.1	47.6	48.1	44.6	37.1	31.8	27.3	34.9
Average	27.2	29.3	32.4	37.5	44.0	48.6	54.0	54.2	49.9	42.2	36.0	31.3	40.6
						Inches							
Precipitation	11.83	11.63	12.36	10.81	6.90	4.18	4.01	5.80	13.83	23.71	22.17	18.72	145.95

BEAVER FALLS: 56

Period: 1957-71 | Mean annual degree days above 41 °F: 2,523 | Mean frost-free period: 186 days

Latitude: 55° 23' N. | Longitude: 131° 28' W. | Elevation: 35 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	35.6	40.6	42.5	49.1	56.3	61.7	65.7	64.7	59.0	50.5	42.3	37.9	50.5
Minimum	26.2	30.8	31.5	35.0	40.8	47.7	51.7	51.7	47.8	40.7	33.8	29.4	39.0
Average	30.9	35.7	37.0	42.1	48.6	54.7	58.7	58.2	53.4	45.6	38.1	33.7	44.8
						Inches							
Precipitation	14.45	11.96	11.02	10.43	6.83	5.92	6.16	10.63	15.66	24.16	17.15	16.30	150.67

BELL ISLAND: 51

Period: 1934-48 | Mean annual degree days above 41 °F: 2,567 | Mean frost-free period: 173 days

Latitude: 55° 55' N. | Longitude: 131° 35' W. | Elevation: 10 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	33.9	34.9	40.6	45.6	59.8	66.0	67.4	66.8	59.7	49.7	40.2	36.2	50.1
Minimum	26.1	24.7	28.7	32.6	38.7	47.1	50.9	50.2	46.5	40.3	32.3	28.4	37.2
Average	30.0	29.8	34.7	39.1	49.3	56.6	59.2	58.5	53.1	45.0	36.3	32.3	43.7
	Inches												
Precipitation	11.42	5.99	8.37	6.77	4.97	4.91	5.60	7.85	11.55	17.34	12.47	11.19	108.43

CALDER: 48

Period: 1917-31 | Mean annual degree days above 41 °F: 1,907 | Mean frost-free period: 126 days

Latitude: 56° 10' N. | Longitude: 132° 27' W. | Elevation: 20 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	35.1	37.2	40.7	48.2	54.0	59.5	61.5	62.7	59.5	49.4	42.0	36.4	48.8
Minimum	26.3	27.2	27.8	31.5	36.9	42.8	46.7	48.2	42.9	38.4	32.6	27.9	35.8
Average	30.7	32.2	34.3	39.9	45.5	51.2	54.1	55.5	51.2	43.9	37.3	32.2	42.3
	Inches												
Precipitation	11.00	9.14	8.43	7.69	5.85	3.63	3.38	6.63	10.13	17.34	16.06	13.48	112.76

CAPE DECISION: 50

Period: 1957-71 | Mean annual degree days above 41 °F: 1,888 | Mean frost-free period: 198 days

Latitude: 56° 00' N. | Longitude: 134° 08' W. | Elevation: 39 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	37.5	41.6	42.3	46.3	50.5	54.0	56.6	57.3	54.8	50.1	43.9	39.7	47.9
Minimum	29.6	34.3	34.5	37.3	41.3	46.2	49.0	49.7	47.9	42.5	36.1	32.4	40.1
Average	33.6	38.0	38.4	41.8	45.9	50.1	52.8	53.5	51.4	46.3	40.0	36.1	44.0
	Inches												
Precipitation	6.72	6.33	4.81	4.54	4.21	3.63	3.54	5.13	7.30	11.24	7.28	8.12	72.85

CAPE HINCHINBROOK: 17

Period: 1957-71 | Mean annual degree days above 41 °F: 1,760 | Mean frost-free period: 186 days

Latitude: 60° 14' N. | Longitude: 146° 39' W. | Elevation: 185 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	33.9	36.5	36.7	41.7	48.4	55.7	58.0	58.7	54.0	46.0	39.9	35.5	45.4
Minimum	27.5	29.9	29.0	33.5	39.9	46.0	50.3	51.2	47.0	38.6	33.2	28.8	37.9
Average	30.7	33.2	32.8	37.6	44.2	50.8	54.1	55.0	50.5	42.3	36.6	32.2	41.6
	Inches												
Precipitation	6.92	7.92	5.75	6.71	7.50	4.95	9.87	10.26	14.62	12.84	8.71	10.30	106.35

CAPE SPENCER: 35

Period: 1957-71 | Mean annual degree days above 41 °F: 1,644 | Mean frost-free period: 212 days

Latitude: 58° 12' N. | Longitude: 136° 38' W. | Elevation: 81 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	34.1	37.2	38.3	43.9	49.0	52.9	55.8	56.8	53.0	46.8	40.2	36.5	45.4
Minimum	28.8	32.4	32.5	36.8	41.3	46.0	48.3	48.8	46.4	41.2	35.0	31.0	39.0
Average	31.5	34.8	35.4	40.4	45.2	49.5	52.1	52.8	49.7	44.0	37.6	33.8	42.2
	Inches												
Precipitation	6.61	7.06	6.89	6.03	6.80	4.35	7.21	8.53	13.47	14.03	11.16	9.72	101.86

CAPE ST. ELIAS: 21

Period: 1957-71 | Mean annual degree days above 41 °F: 1,800 | Mean frost-free period: 177 days

Latitude: 59° 48' N. | Longitude: 144° 36' W. | Elevation: 58 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	34.9	37.7	38.2	43.3	48.7	54.3	57.7	58.6	55.3	47.9	40.7	36.6	46.2
Minimum	28.0	31.2	30.0	34.7	40.3	46.4	50.0	50.8	46.9	39.0	33.3	29.8	38.4
Average	31.4	34.4	34.1	39.0	44.5	50.4	53.9	54.7	51.1	43.5	37.0	33.2	42.3
	Inches												
Precipitation	7.52	7.67	7.11	6.88	6.91	4.41	9.32	8.62	13.24	12.86	9.49	11.29	105.32

CORDOVA FAA AP: 20

Period: 1957-71 | Mean annual degree days above 41 °F: 1,600 | Mean frost-free period: 110 days

Latitude: 60° 30' N. | Longitude: 145° 30' W. | Elevation: 41 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	29.9	35.5	37.0	44.2	52.0	58.4	60.6	61.2	55.9	46.6	37.5	32.0	45.9
Minimum	13.2	20.1	20.3	28.8	35.7	43.3	46.8	45.5	40.3	32.0	24.2	17.5	30.6
Average	21.6	27.8	28.7	36.5	43.9	50.9	53.7	53.4	48.1	39.3	30.9	24.8	38.2
						Inches							
Precipitation	4.71	6.89	5.69	5.63	6.49	5.22	7.48	9.03	12.46	11.56	7.36	7.44	89.96

CRAIG: 55

Period: 1938-52 | Mean annual degree days above 41 °F: 2,341 | Mean frost-free period: 177 days

Latitude: 55° 29' N. | Longitude: 133° 09' W. | Elevation: 13 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	39.5	40.9	44.0	49.0	55.9	59.7	62.7	63.4	59.5	51.5	44.4	40.5	50.9
Minimum	29.5	30.2	31.2	35.2	40.2	45.4	50.4	50.0	47.0	41.1	34.8	31.4	38.9
Average	34.5	35.6	37.6	42.1	48.1	52.6	56.6	56.7	53.3	46.3	39.6	36.0	44.9
						Inches							
Precipitation	12.16	7.69	8.58	8.80	5.22	3.73	4.48	5.75	9.47	14.62	13.49	11.98	105.97

DUTCH HARBOR: 4

Period: 1930-34 | Mean annual degree days above 41 °F: 1,351 | Mean frost-free period: 158 days

Latitude: 53° 55' N. | Longitude: 166° 30' W. | Elevation: 47 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	36.3	36.7	37.8	41.6	46.2	51.2	56.9	60.0	54.0	46.6	41.4	36.9	45.5
Minimum	28.1	28.1	28.7	31.5	35.9	41.1	45.4	48.1	44.5	38.2	32.7	28.8	35.9
Average	32.2	32.4	33.3	36.6	41.1	46.2	51.2	54.1	49.3	42.4	37.1	32.9	40.7
						Inches							
Precipitation	6.97	7.01	4.58	4.40	4.35	2.81	1.60	2.45	6.16	7.13	6.01	6.72	60.19

ELDRED ROCK: 27

Period: 1957-71 | Mean annual degree days above 41 °F: 2,034 | Mean frost-free period: 184 days

Latitude: 58° 58' N. | Longitude: 135° 13' W. | Elevation: 55 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	29.2	35.2	36.5	44.6	52.1	59.5	61.4	60.7	54.6	46.4	37.6	32.7	45.9
Minimum	22.3	27.0	28.4	35.7	41.6	49.0	51.7	50.8	45.2	37.1	29.4	25.0	36.9
Average	25.8	31.1	32.5	40.2	46.9	54.3	56.6	55.8	49.9	41.8	33.5	28.9	41.4
	Inches												
Precipitation	4.15	4.75	2.70	1.93	2.52	1.76	2.61	3.36	6.75	7.99	5.63	4.57	48.72

FIVE FINGER LIGHT STATION: 40

Period: 1957-71 | Mean annual degree days above 41 °F: 1,901 | Mean frost-free period: 187 days

Latitude: 57° 16' N. | Longitude: 133° 37' W. | Elevation: 30 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	34.7	39.0	40.3	46.3	52.3	57.5	59.0	58.8	54.0	48.3	41.6	37.6	47.4
Minimum	27.4	31.3	32.8	36.3	40.7	46.7	49.6	47.9	45.8	40.8	34.5	30.5	38.7
Average	31.1	35.2	36.6	41.3	46.5	52.1	54.3	53.4	49.9	44.6	38.1	34.1	43.1
	Inches												
Precipitation	4.78	4.42	2.97	3.21	2.69	2.70	3.78	5.57	6.07	8.76	6.43	6.13	57.51

FORTMAN HATCHERY: 52

Period: 1912-26 | Mean annual degree days above 41 °F: 2,572 | Mean frost-free period: 150 days

Latitude: 55° 36' N. | Longitude: 131° 25' W. | Elevation: 132 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	34.4	38.9	43.8	51.0	59.3	66.1	68.3	68.2	61.6	52.1	[illegible]	36.3	[illegible]
Minimum	23.7	24.3	27.6	32.6	37.9	44.8	49.2	49.9	44.6	39.6	[illegible]	26.6	[illegible]
Average	29.1	31.6	35.7	41.8	48.6	55.5	58.8	59.1	53.1	[illegible]	38.2	31.5	[illegible]
	Inches												
Precipitation	12.16	12.61	11.75	11.24	8.37	5.31	6.88	8.59	12.03	19.20	20.67	16.39	145.20

GUARD ISLAND: 53

Period: 1957-68 | Mean annual degree days above 41 °F: 2,695 | Mean frost-free period: 187 days

Latitude: 55° 27' N. | Longitude: 131° 53' W. | Elevation: 20 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	38.6	41.5	42.7	48.7	55.3	59.9	64.2	63.8	58.5	50.6	43.1	40.3	50.6
Minimum	31.6	34.0	34.4	38.0	43.0	49.1	53.3	54.0	50.2	44.1	36.6	34.7	42.0
Average	35.1	37.8	38.6	43.4	49.2	54.5	58.8	58.9	54.4	47.4	39.9	37.5	46.3
	Inches												
Precipitation	5.43	5.00	4.59	3.78	3.80	3.40	3.53	4.52	6.08	10.81	6.61	6.12	63.67

GULL COVE: 36

Period: 1941-52 | Mean annual degree days above 41 °F: 1,721 | Mean frost-free period: 158 days

Latitude: 58° 12' N. | Longitude: 136° 09' W. | Elevation: 18 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	34.1	35.9	39.3	45.0	53.5	58.4	60.1	59.9	55.0	47.4	39.0	34.8	46.9
Minimum	24.2	25.9	28.9	32.9	38.2	44.1	47.2	47.2	43.9	37.3	30.2	25.5	35.4
Average	29.2	30.9	34.1	39.0	45.8	51.3	53.7	53.6	49.5	42.4	34.6	30.2	41.1
	Inches												
Precipitation	11.16	6.07	8.79	5.46	3.78	2.86	5.17	5.09	11.40	17.32	12.88	9.57	99.55

GUSTAVUS: 34

Period: 1956-68 | Mean annual degree days above 41 °F: 1,872 | Mean frost-free period: 114 days

Latitude: 58° 25' N. | Longitude: 135° 44' W. | Elevation: 17 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	31.6	36.0	39.0	47.6	55.0	60.4	63.0	63.0	56.9	47.7	38.9	33.6	47.7
Minimum	19.6	23.5	25.6	31.6	37.8	45.0	48.8	48.1	43.1	37.1	28.8	23.7	34.4
Average	25.6	29.8	32.3	39.6	46.4	52.7	55.9	55.6	50.0	42.4	33.9	28.7	41.1
	Inches												
Precipitation	3.71	3.44	2.33	2.14	2.80	2.58	4.20	5.56	6.84	8.32	6.30	5.96	54.18

HAINES TERMINAL: 26

Period: 1957-71 | Mean annual degree days above 41 °F: 2,103 | Mean frost-free period: 148 days

Latitude: 59° 16' N. | Longitude: 135° 27' W. | Elevation: 175 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	26.9	35.2	37.8	48.4	56.5	63.8	64.3	62.8	56.8	47.1	37.1	31.9	47.4
Minimum	16.0	24.3	25.3	32.1	39.2	47.1	50.4	48.8	43.7	35.7	26.6	21.8	34.2
Average	21.5	29.8	31.6	40.3	47.8	55.5	57.4	55.8	50.3	41.4	31.9	26.9	40.8
	Inches												
Precipitation	4.56	4.40	4.43	2.34	2.29	1.33	1.79	2.75	6.17	8.60	5.96	6.68	51.30

HOLLIS: 54

Period: 1954-62 | Mean annual degree days above 41 °F: 2,352 | Mean frost-free period: 149 days

Latitude: 55° 28' N. | Longitude: 132° 40' W. | Elevation: 15 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	36.5	38.0	42.1	48.3	57.5	61.9	66.8	65.5	59.3	49.6	42.1	37.6	50.4
Minimum	27.4	28.0	29.8	33.0	39.5	45.7	49.9	50.1	44.6	39.4	33.6	30.0	37.6
Average	31.9	33.0	36.0	40.7	48.5	53.8	58.4	57.8	52.0	44.5	37.9	33.8	44.0
	Inches												
Precipitation	8.68	8.81	7.25	7.59	4.54	3.64	3.11	4.98	7....	17.90	.....	12.62	100.25

HOMER WSO: 10

Period: 1957-71 | Mean annual degree days above 41 °F: 1,397 | Mean frost-free period: 108 days

Latitude: 59° 38' N. | Longitude: 151° 30' W. | Elevation: 67 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	27.2	32.3	34.8	42.2	50.5	56.7	60.1	60.0	54.7	43.9	.....	28.2	43.8
Minimum	14.7	18.9	19.6	28.4	34.2	41.3	45.3	45.1	39.4	29.9	22.7	16.4	29.6
Average	21.0	25.6	27.2	35.3	42.4	49.0	52.8	52.6	47.1	36.9	28.8	22.3	36.7
	Inches												
Precipitation	1.38	1.98	1.30	1.21	1.10	.95	1.87	2.30	2.87	3.18	2.56	2.66	23.36

JUNEAU WSO AP: 31

Period: 1957-71 | Mean annual degree days above 41 °F: 1,845 | Mean frost-free period: 131 days

Latitude: 58° 22' N. | Longitude: 134° 35' W. | Elevation: 12 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	27.7	35.0	37.9	46.9	55.0	61.6	63.4	62.0	55.6	47.2	37.1	32.0	46.8
Minimum	16.1	22.7	25.4	31.0	37.7	44.2	47.2	46.3	42.2	36.0	27.1	22.3	33.2
Average	21.9	28.9	31.7	39.0	46.4	52.9	55.3	54.2	48.9	41.6	32.1	27.2	40.0
						Inches							
Precipitation	4.00	3.86	3.50	2.91	3.51	2.77	4.76	5.22	6.79	6.78	5.05	4.70	53.85

JUNEAU NO. 2: 30

Period: 1957-71 | Mean annual degree days above 41 °F: 2,344 | Mean frost-free period: 167 days

Latitude: 58° 18' N. | Longitude: 134° 24' W. | Elevation: 25 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	30.8	37.6	40.1	48.9	57.1	64.0	65.0	63.9	57.0	48.7	39.2	36.2	49.0
Minimum	21.5	27.6	29.2	34.4	41.1	46.8	50.2	49.5	45.8	39.0	30.5	27.0	36.9
Average	26.2	32.6	34.7	41.7	49.1	55.4	57.6	56.7	51.4	43.9	34.9	31.6	43.0
						Inches							
Precipitation	6.49	6.82	6.07	5.90	6.00	3.79	7.27	8.18	11.47	12.69	9.64	8.30	92.62

JUNEAU 9 NW (MENDENHALL): 32

Period: 1939-43 & 1966-70 | Mean annual degree days above 41 °F: 1,454 | Mean frost-free period: 125 days

Latitude: 58° 25' N. | Longitude: 134° 32' W. | Elevation: 120 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	28.0	37.1	41.2	48.8	54.4	59.0	58.7	57.7	54.1	47.1	37.4	33.2	46.4
Minimum	10.3	21.1	25.8	31.9	37.2	42.4	44.7	43.3	40.3	36.1	26.7	23.4	31.9
Average	19.2	29.1	33.5	40.4	45.8	50.7	51.7	50.5	47.2	41.6	32.0	28.3	39.2
						Inches							
Precipitation	6.23	4.67	4.55	4.05	5.16	4.51	7.08	9.33	12.63	11.50	7.46	6.26	83.43

KAKE: 43

Period: 1920-23 & 1930-34 | Mean annual degree days above 41 °F: 1,826 | Mean frost-free period: 151 days

Latitude: 56° 59' N. | Longitude: 133° 57' W. | Elevation: 8 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	34.8	37.2	39.9	46.6	52.3	59.2	60.6	62.1	56.1	49.2	43.4	37.0	48.2
Minimum	25.8	26.8	28.8	33.1	38.0	44.1	46.4	48.6	43.4	37.4	32.1	27.2	36.0
Average	30.3	32.0	34.4	39.9	45.2	51.7	53.5	55.4	49.8	43.3	37.8	32.1	42.1
	Inches												
Precipitation	5.19	5.33	2.99	3.86	3.04	2.16	2.51	4.35	5.20	7.30	6.69	5.55	54.17

KENAI FAA MUNICIPAL AP: 12

Period: 1957-71 | Mean annual degree days above 41 °F: 1,540 | Mean frost-free period: 107 days

Latitude: 60° 34' N. | Longitude: 151° 15' W. | Elevation: 86 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	20.0	28.2	32.4	42.3	52.5	58.6	61.5	61.7	55.8	42.9	30.0	21.4	42.3
Minimum	1.7	8.9	11.0	25.7	34.4	42.3	46.8	45.4	38.8	26.3	13.4	5.0	25.0
Average	10.9	18.6	21.7	34.0	43.5	50.5	54.2	53.6	47.3	34.6	21.7	13.2	33.6
	Inches												
Precipitation	1.07	1.06	1.04	.96	1.08	1.18	2.24	2.87	3.13	2.27	1.45	1.60	19.95

KETCHIKAN: 57

Period: 1957-71 | Mean annual degree days above 41 °F: 2,739 | Mean frost-free period: 182 days

Latitude: 55° 21' N. | Longitude: 131° 39' W. | Elevation: 15 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	40.0	44.5	45.5	51.0	58.0	63.0	66.3	65.9	61.0	53.3	45.9	41.7	53.0
Minimum	27.7	32.2	32.6	35.6	40.6	46.8	50.8	50.8	47.2	40.7	34.4	30.8	[illegible]
Average	33.9	38.4	39.1	43.3	49.3	54.9	58.6	[illegible]	54.1	47.0	40.2	36.3	[illegible]
	Inches												
Precipitation	15.20	13.36	11.50	12.62	8.73	6.94	8.15	12.43	14.37	25.53	17.67	16.67	163.17

KITOI BAY: 4

Period: 1957-71 | Mean annual degree days above 41 °F: 1,475 | Mean frost-free period: 127 days

Latitude: 58° 11' N. | Longitude: 152° 21' W. | Elevation: 15 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	33.0	35.7	37.2	42.8	50.0	54.7	59.5	60.5	54.4	44.7	37.7	33.1	45.3
Minimum	23.0	24.5	23.8	29.4	35.8	42.3	47.1	47.5	42.6	32.9	27.8	22.3	33.3
Average	28.0	30.1	30.5	36.1	42.9	48.5	53.3	54.0	48.5	38.8	32.7	27.7	39.3
	Inches												
Precipitation	5.52	4.91	4.34	4.10	4.52	3.76	3.85	5.55	6.59	6.41	5.60	6.21	61.36

KODIAK NAS: 7

Period: 1957-71 | Mean annual degree days above 41 °F: 1,636 | Mean frost-free period: 154 days

Latitude: 57° 45' N. | Longitude: 152° 31' W. | Elevation: 21 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	34.6	36.4	36.8	42.3	49.2	54.9	59.5	60.0	55.2	45.4	39.2	34.2	45.6
Minimum	26.3	27.0	26.5	31.8	38.8	44.8	48.9	49.1	44.9	35.1	30.5	25.3	35.8
Average	30.5	31.7	31.7	37.1	44.0	49.9	54.2	54.6	50.1	40.3	34.9	29.8	40.7
	Inches												
Precipitation	5.21	5.26	3.91	3.26	2.96	4.75	3.86	5.12	6.65	5.45	5.42	5.86	57.71

LARSEN BAY: 5

Period: 1957-65 | Mean annual degree days above 41 °F: 1,638 | Mean frost-free period: 135 days

Latitude: 57° 32' N. | Longitude: 154° 00' W. | Elevation: 15 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	36.6	37.6	38.9	44.1	49.7	60.2	61.2	61.4	57.7	46.1	39.6	34.6	47.3
Minimum	24.4	23.9	25.4	29.1	34.7	42.9	46.8	47.1	42.7	33.4	28.1	22.4	33.4
Average	30.5	30.8	32.1	36.6	42.2	51.5	54.0	54.3	50.2	39.8	33.9	28.5	40.4
	Inches												
Precipitation	2.03	1.58	1.41	1.32	.84	.76	1.46	2.15	2.92	2.61	3.37	2.48	22.93

LATOUCHE: 16

Period: 1940-55 | Mean annual degree days above 41 °F: 1,[illegible] | Mean frost-free period: [illegible]

Latitude: 60° 03' N. | Longitude: 147° 54' W. | Elevation: [illegible]

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	33.5	35.8	37.9	42.2	[illegible]	55.5	61.0	[illegible]	55.1	46.2	38.6	34.1	45.8
Minimum	26.1	27.2	27.6	31.2	37.0	43.5	48.1	49.1	44.4	37.0	31.4	27.0	35.8
Average	29.8	31.5	32.8	36.7	42.9	49.5	54.6	54.8	49.8	41.6	35.0	30.6	40.8
	Inches												
Precipitation	16.53	14.23	14.15	14.99	11.40	6.88	6.19	11.42	17.78	[illegible]	16.94	16.75	170.62

LINCOLN ROCK: 49

Period: 1953-67 | Mean annual degree days above 41 °F: [illegible] | Mean frost-free period: 194 days

Latitude: 56° 03' N. | Longitude: 132° 46' W. | Elevation: 25 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	38.3	40.8	41.9	47.6	53.5	58.7	62.6	62.3	57.2	50.0	43.6	40.0	49.7
Minimum	29.6	32.1	32.7	36.9	42.6	47.2	51.0	52.1	48.3	42.0	35.7	32.2	[illegible]
Average	34.0	36.5	37.3	42.3	48.1	53.0	56.8	57.2	52.8	46.0	39.6	36.1	44.9
	Inches												
Precipitation	5.44	6.00	4.50	3.74	3.38	2.94	3.19	4.50	6.55	10.42	7.90	8.67	67.23

LINGER LONGER: 25

Period: 1960-71 | Mean annual degree days above 41 °F: 1,989 | Mean frost-free period: 107 days

Latitude: 59° 26' N. | Longitude: 136° 17' W. | Elevation: 700 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	20.6	[illegible]	36.1	46.5	58.3	66.7	69.2	66.5	57.0	[illegible]	29.8	[illegible]	45.6
Minimum	[illegible]	16.0	18.7	27.7	33.7	42.1	46.8	45.1	40.3	31.7	[illegible]	9.1	28.0
Average	13.5	23.5	27.4	37.1	46.0	54.4	58.0	55.8	[illegible]	38.1	24.1	15.3	[illegible]
	Inches												
Precipitation	2.74	4.05	2.24	1.56	1.96	.78	1.20	1.97	4.66	6.26	3.78	2.64	33.84

LITTLE PORT WALTER: 46

Period: 1957-71 | Mean annual degree days above 41 °F: 1,888 | Mean frost-free period: 172 days

Latitude: 56° 23' N. | Longitude: 134° 39' W. | Elevation: 14 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	35.0	39.4	40.9	45.9	51.9	57.0	60.7	60.2	55.7	48.7	41.6	37.6	47.9
Minimum	27.3	31.2	31.6	34.0	39.1	44.9	48.9	48.6	45.7	40.0	34.0	30.2	38.0
Average	31.2	35.3	36.2	40.0	45.5	51.0	54.8	54.4	50.7	44.4	37.8	33.9	43.0
						Inches							
Precipitation	19.75	20.48	15.92	14.61	12.55	8.47	9.43	14.77	24.46	33.45	26.26	26.94	227.09

MIDDLETON ISLAND: 19

Period: 1943-58 | Mean annual degree days above 41 °F: 1,628 | Mean frost-free period: 204 days

Latitude: 59° 28' N. | Longitude: 146° 19' W. | Elevation: 39 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	36.5	36.6	38.1	42.6	46.6	51.9	56.4	58.0	54.4	47.5	42.0	37.8	45.7
Minimum	30.7	30.6	31.4	34.4	39.1	44.2	48.7	50.3	47.2	40.8	36.0	31.7	38.8
Average	33.6	33.6	34.8	38.5	42.9	48.1	52.6	54.2	50.8	44.2	39.0	34.8	42.2
						Inches							
Precipitation	5.32	3.94	3.35	3.27	3.62	2.23	3.45	4.81	7.13	8.18	6.93	5.78	58.01

PETERSBURG: 44

Period: 1957-71 | Mean annual degree days above 41 °F: 2,005 | Mean frost-free period: 140 days

Latitude: 56° 49' N. | Longitude: 132° 57' W. | Elevation: 50 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	31.4	37.9	41.0	48.5	55.8	61.5	63.7	62.7	56.8	48.8	39.3	34.8	48.5
Minimum	21.3	26.4	28.2	32.4	38.1	44.6	47.7	46.7	43.4	38.0	29.6	25.7	35.2
Average	26.4	32.2	34.6	40.5	47.0	53.1	55.7	54.7	50.1	43.4	34.5	30.3	41.9
						Inches							
Precipitation	9.33	7.96	6.56	7.37	5.85	5.15	5.68	7.26	11.52	16.99	11.03	11.70	106.40

POINT RETREAT LIGHT STATION: 33

Period: 1957-71 | Mean annual degree days above 41 °F: 2,110 | Mean frost-free period: 173 days

Latitude: 58° 25' N. | Longitude: 134° 57' W. | Elevation: 20 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	31.5	36.3	38.4	46.2	53.4	60.7	62.7	61.8	55.3	47.3	39.0	34.9	47.3
Minimum	23.4	28.4	29.9	35.0	40.6	46.2	50.8	50.4	46.5	39.2	31.1	27.5	37.5
Average	27.5	32.4	34.2	40.6	47.0	53.5	56.8	56.1	50.9	43.3	35.1	31.2	42.4
						Inches							
Precipitation	5.08	5.07	3.92	4.36	4.12	2.72	5.79	6.18	9.82	10.03	7.07	6.25	70.41

PORT ALEXANDER: 47

Period: 1950-61 | Mean annual degree days above 41 °F: 2,058 | Mean frost-free period: 175 days

Latitude: 56° 15' N. | Longitude: 134° 39' W. | Elevation: 18 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	35.4	38.1	40.6	46.9	53.5	59.9	63.8	62.4	56.9	48.7	42.4	38.9	49.0
Minimum	28.2	30.8	31.7	35.5	40.3	44.6	47.9	48.2	44.9	40.2	35.3	32.1	38.3
Average	31.8	34.5	36.2	41.2	46.9	52.3	55.9	55.3	50.9	44.5	38.9	35.5	43.6
						Inches							
Precipitation	14.62	14.82	12.81	10.71	9.35	6.91	9.38	13.72	15.81	22.63	19.05	19.52	169.33

RADIOVILLE : 38

Period: 1936-50 | Mean annual degree days above 41 °F: 2,355 | Mean frost-free period: 192 days

Latitude: 57° 36' N. | Longitude: 136° 09' W. | Elevation: 15 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	39.0	38.5	45.2	50.7	55.9	60.4	62.7	61.5	59.6	51.6	43.8	38.8	50.6
Minimum	30.0	28.6	32.6	36.5	40.8	45.7	49.4	49.1	47.0	41.2	35.0	30.7	38.9
Average	34.5	33.6	38.9	43.6	48.4	53.1	56.1	55.3	53.3	46.4	39.4	34.8	44.8
						Inches							
Precipitation	10.17	5.81	7.68	5.76	5.28	4.58	8.17	9.02	14.03	17.33	14.25	10.71	112.79

SEWARD: 14

Period: 1957-71

Mean annual degree days above 41 °F: 1,847

Mean frost-free period: 152 days

Latitude: 60° 07' N.

Longitude: 149° 27' W.

Elevation: 70 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	28.9	34.0	36.5	45.1	53.0	59.5	62.5	62.5	55.9	44.8	34.0	30.2	45.6
Minimum	18.7	23.5	24.0	32.0	38.3	45.3	49.3	49.0	43.8	34.2	26.8	20.8	33.8
Average	23.8	28.8	30.3	38.6	45.7	52.4	55.9	55.8	49.9	39.5	30.4	25.5	39.7
						Inches							
Precipitation	3.45	4.85	3.32	2.96	3.67	2.64	3.32	5.15	10.06	9.12	6.28	6.35	61.17

SITKA FAA AP: 42

Period: 1957-71

Mean annual degree days above 41 °F: 2,244

Mean frost-free period: 191 days

Latitude: 57° 04' N.

Longitude: 135° 21' W.

Elevation: 15 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	37.1	41.7	42.5	47.5	53.5	57.6	60.6	61.8	57.8	50.5	43.3	39.0	49.4
Minimum	28.6	32.6	32.6	35.7	41.0	46.9	50.8	51.5	47.8	41.4	35.1	32.2	39.4
Average	32.9	37.2	37.6	41.6	47.3	52.3	55.7	56.7	52.8	46.0	39.2	35.6	44.6
						Inches							
Precipitation	7.25	6.10	5.93	5.87	4.85	3.95	5.44	7.73	10.93	12.42	9.94	8.16	88.17

SKAGWAY: 24

Period: 1922-36

Mean annual degree days above 41 °F: 2,175

Mean frost-free period: 111 days

Latitude: 59° 28' N.

Longitude: 135° 19' W.

Elevation: 18 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	29.6	30.4	38.7	48.5	58.6	66.9	66.7	65.5	57.8	47.9	39.4	29.4	48.4
Minimum	19.6	19.6	26.3	31.6	38.8	44.6	48.3	46.9	40.8	36.0	28.5	19.8	33.4
Average	24.6	25.0	32.5	40.1	48.7	55.8	57.5	56.2	49.4	42.0	34.0	24.6	40.9
						Inches							
Precipitation	2.76	1.75	1.71	1.65	1.21	.93	1.64	1.96	3.53	5.08	4.70	3.29	30.21

SOLDOTNA 6 W.: 11

Period: 1962-71 | Mean annual degree days above 41 °F: 1,592 | Mean frost-free period: 94 days

Latitude: 60° 28' N. | Longitude: 151° 14' W. | Elevation: 85 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	19.2	27.1	34.0	43.8	53.7	61.5	65.8	64.1	57.6	42.0	28.0	20.9	43.1
Minimum	-2.5	3.4	6.3	24.5	32.3	42.1	45.0	43.4	35.1	21.0	7.6	1.3	21.6
Average	8.4	15.3	20.2	34.2	43.0	51.8	55.4	53.8	46.4	31.5	17.8	11.1	32.4
	Inches												
Precipitation	.89	2.73	1.23	.71	1.12	1.53	1.65	2.49	1.89	2.12	.71	1.49	18.56

TAKU PASS (CANYON ISLAND): 28

Period: 1936-44 | Mean annual degree days above 41 °F: 2,138 | Mean frost-free period: 136 days

Latitude: 58° 33' N. | Longitude: 133° 40' W. | Elevation: 175 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	26.7	28.0	39.0	51.4	60.0	66.3	65.5	64.4	57.7	48.3	33.7	26.7	47.3
Minimum	15.6	16.6	24.0	32.9	39.0	43.8	45.7	44.9	42.1	36.6	24.5	18.3	32.0
Average	21.2	22.3	31.5	42.2	49.5	55.1	55.6	54.7	49.9	42.5	29.1	22.5	39.7
	Inches												
Precipitation	6.81	3.66	3.65	2.54	2.14	2.15	2.79	4.05	6.36	11.21	8.50	6.84	60.70

TENAKEE: 37

Period: 1941-50 | Mean annual degree days above 41 °F: 2,158 | Mean frost-free period: 146 days

Latitude: 57° 47' N. | Longitude: 135° 15' W. | Elevation: 19 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	33.9	36.2	41.8	46.9	57.3	63.0	63.4	64.7	59.1	49.1	38.7	34.5	49.0
Minimum	23.3	25.3	29.3	33.0	38.5	44.5	47.9	47.8	44.9	37.6	28.5	26.1	[illegible]
Average	28.6	30.8	35.6	40.0	47.9	53.8	55.7	56.3	52.0	[illegible]	33.6	30.3	[illegible]
	Inches												
Precipitation	5.07	3.87	4.32	3.29	2.72	2.48	4.71	4.66	7.75	11.28	7.18	5.87	63.20

TREE POINT LIGHT STATION: 60

Period: 1957-70 | Mean annual degree days above 41 °F: 2,554 | Mean frost-free period: 199 days

Latitude: 54° 48' N. | Longitude: 130° 56' W. | Elevation: 36 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	39.3	44.8	45.4	50.1	55.1	59.5	62.6	63.2	59.3	53.1	45.4	42.2	51.7
Minimum	28.4	33.1	33.2	37.1	42.2	48.3	51.6	51.3	48.2	42.8	35.8	32.1	40.3
Average	33.9	39.0	39.3	43.6	48.7	53.9	57.1	57.3	53.8	48.0	40.6	37.2	46.0
						Inches							
Precipitation	9.55	8.92	7.33	7.22	4.69	4.56	5.06	7.23	9.82	15.80	11.61	11.08	102.87

UGANIK BAY: 6

Period: 1952-64 | Mean annual degree days above 41 °F: 1,749 | Mean frost-free period: 121 days

Latitude: 57° 43' N. | Longitude: 153° 19' W. | Elevation: 50 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	35.7	37.2	38.5	44.5	52.8	60.9	64.4	64.2	56.7	47.3	39.9	34.3	48.0
Minimum	24.2	24.0	24.4	29.6	35.6	42.4	47.2	45.9	40.2	33.1	27.9	22.6	33.1
Average	30.0	30.6	31.5	37.1	44.2	51.7	55.8	55.1	48.5	40.2	33.9	28.5	40.6
						Inches							
Precipitation	4.21	3.18	2.61	3.39	2.75	1.83	2.03	2.44	4.11	6.49	5.91	5.16	44.11

VALDEZ: 18

Period: 1957-71 | Mean annual degree days above 41 °F: 1,611 | Mean frost-free period: 124 days

Latitude: 61° 08' N. | Longitude: 146° 21' W. | Elevation: 20 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
						(°F)							
Maximum	25.7	31.4	35.8	45.8	54.0	60.7	61.9	60.8	54.8	44.1	33.1	26.3	44.5
Minimum	10.9	15.6	18.7	28.9	36.1	44.0	46.5	45.0	38.6	30.8	20.0	13.1	29.0
Average	18.3	23.5	27.3	37.4	45.1	52.4	54.2	52.9	46.7	37.5	26.6	19.7	36.8
						Inches							
Precipitation	3.90	4.89	4.77	2.61	3.27	2.31	4.05	5.46	7.65	7.25	6.34	4.65	57.15

VIEW COVE: 58

Period: 1933-46 | Mean annual degree days above 41 °F: 2,725 | Mean frost-free period: 208 days

Latitude: 55° 04' N. | Longitude: 133° 04' W. | Elevation: 13 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	41.6	41.8	45.4	51.3	57.2	62.5	62.6	65.9	62.5	54.6	47.1	42.0	52.9
Minimum	32.5	30.8	32.5	37.4	41.2	46.2	49.9	50.9	47.7	42.6	37.3	32.7	40.1
Average	37.1	36.3	39.0	44.4	49.2	54.4	56.3	58.4	55.1	48.6	42.2	37.4	46.5
	Inches												
Precipitation	20.26	12.36	13.52	12.16	7.73	5.18	6.05	7.53	11.89	22.04	22.64	19.55	160.91

WHALE ISLAND: 8

Period: 1924-38 | Mean annual degree days above 41 °F: 1,501 | Mean frost-free period: 107 days

Latitude: 57° 58' N. | Longitude: 152° 46' W. | Elevation: 8 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	34.7	35.0	38.1	42.0	48.2	55.6	59.8	60.9	55.8	47.1	40.3	35.1	46.1
Minimum	22.9	22.9	25.2	30.3	36.2	42.5	46.5	47.5	42.0	34.8	27.5	24.0	33.5
Average	28.8	29.0	31.7	36.2	42.2	49.1	53.2	54.2	48.9	41.0	33.9	29.6	39.8
	Inches												
Precipitation	3.87	4.62	2.84	3.52	6.88	4.22	3.16	3.46	3.70	6.74	5.48	4.74	53.23

WHITTIER: 15

Period: 1957-71 | Mean annual degree days above 41 °F: 1,624 | Mean frost-free period: 144 days

Latitude: 60° 47' N. | Longitude: 148° 41' W. | Elevation: 31 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	29.8	33.1	33.6	42.4	50.1	58.3	60.1	60.1	53.4	42.3	34.0	29.4	43.9
Minimum	20.6	23.0	22.8	31.0	36.5	45.0	48.5	48.1	42.1	32.2	24.9	20.6	[illegible]
Average	25.2	28.1	28.2	36.7	43.3	51.7	54.3	54.1	47.8	[illegible]	[illegible]	25.0	38.4
	Inches												
Precipitation	12.22	10.03	12.23	13.16	15.22	9.88	13.77	13.17	16.86	19.38	18.31	[illegible]	177.91

WRANGELL: 45

Period: 1957-71 | Mean annual degree days above 41 °F: 2,144 | Mean frost-free period: 169 days

Latitude: 56° 28' N. | Longitude: 132° 23' W. | Elevation: 37 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	32.1	38.6	41.6	48.2	55.7	61.1	63.4	63.6	57.0	49.4	40.7	35.9	48.9
Minimum	21.7	27.8	29.7	34.3	39.0	44.9	47.8	47.2	43.5	37.2	30.0	25.8	35.7
Average	26.9	33.2	35.7	41.3	47.4	53.0	55.6	54.9	50.3	43.3	35.4	30.9	42.3
	Inches												
Precipitation	6.36	5.92	7.10	4.85	3.95	4.28	4.74	6.07	8.60	13.14	9.00	7.74	81.75

YAKATAGA FAA: 22

Period: 1953-67 | Mean annual degree days above 41 °F: 1,454 | Mean frost-free period: 141 days

Latitude: 60° 05' N. | Longitude: 142° 30' W. | Elevation: 27 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	33.6	35.9	37.8	43.4	49.0	54.4	57.5	57.9	54.5	46.8	39.0	34.4	45.3
Minimum	23.0	24.5	25.3	30.6	37.1	44.0	48.1	47.6	42.7	35.1	29.2	24.6	34.3
Average	28.3	30.2	31.6	37.0	43.1	49.2	52.8	52.8	48.6	41.0	34.1	29.5	39.8
	Inches												
Precipitation	6.33	8.00	4.78	4.96	5.46	4.14	5.98	8.95	11.72	14.70	10.90	10.93	96.85

YAKUTAT WSO AP: 23

Period: 1957-71 | Mean annual degree days above 41 °F: 1,447 | Mean frost-free period: 110 days

Latitude: 59° 31' N. | Longitude: 139° 40' W. | Elevation: 28 feet

Mean temperature	Month												Mean annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
	(°F)												
Maximum	30.1	35.3	37.4	43.5	50.2	56.4	59.8	59.7	55.0	47.0	37.5	32.6	45.3
Minimum	15.7	21.4	21.6	28.5	35.2	43.4	47.2	45.7	40.9	33.3	25.7	20.2	31.6
Average	22.9	28.4	29.5	36.0	42.7	49.9	53.0	52.7	48.2	40.2	31.6	26.4	38.4
	Inches												
Precipitation	9.51	11.09	9.87	8.15	9.02	6.00	10.36	10.46	15.26	19.46	14.01	13.86	137.05

Farr, Wilbur A.; Hard, John S. Multivariate analysis of climate along the southern coast of Alaska—some forestry implications. Res. Pap. PNW-RP-372. Portland, OR: U.S. Deparment of Agriculture, Forest Service, Pacific Northwest Research Station; **1987.** 38 p.

A multivariate analysis of climate was used to delineate 10 significantly different groups of climatic stations along the southern coast of Alaska based on latitude,longitude, seasonal temperatures and precipitation, frost-free periods, and total number of growing degree days. The climatic stations were too few to delineate this rugged, mountainous region into distinct climatic zones.

Keywords: Climate, multivariate analysis, coastal Alaska, Alaska (coastal).

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Behavior of Mule Deer on the Keating Winter Range

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Abstract

Fowler, W.B.; Dealy, J.E. Behavior of mule deer on the Keating Winter Range. Res. Pap. PNW-RP-373 . Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1987**. 25 p.

Observations are presented from 4 years of record, 1976 to 1979, on behavior of mule deer (*Odocoileus hemionus*) in relation to site variables on the Keating Winter Range in northeastern Oregon. Analyses of animal use per unit area showed that the preferential selection of cells was related primarily to static site variables and secondarily to weather. The most regularly selected and strongest predictive variable was distance from the valley bottom, a variable generally associated with elevation. Only during the midafternoon hours of 1400 to 1600 did dynamic weather variables contribute substantially to the variance explained by the regression equations. For individual cells, animal use was controlled by snow depth and temperature.

Keywords: Animal behavior, winter range, deer (mule).

Summary

Observations are presented from 4 years of record, 1976 to 1979, on behavior of mule deer (*Odocoileus hemionus*) in relation to site variables on the Keating Winter Range in northeastern Oregon. Analyses of animal use per unit area for 100 cells based on landform and vegetation showed that the preferential selection of cells was related primarily to static site variables and secondly to weather. The most regularly selected and strongest predictive variable was distance from the valley bottom, a variable generally associated with elevation. Only during the midafternoon hours of 1400 to 1600 did dynamic weather variables contribute substantially to the variance explained by the regression equations. A subset of the data was available for analyzing the use of each of the cells. Snow depth was the variable controlling animal use, except for cells in the major stream channel. There, temperature controlled the response, and use by deer was greater during falling temperatures. These analyses supported visual observations that animals used more of the area during warm weather and sought out areas where snow was shallower and less crusted. Improvement of winter forage and cover is most feasible near areas of high animal use. Major improvements such as cover, fencing to control snow depth, and forage enhancement would be required to alter the preferential site selection shown by the animals. Major increases in deer population or excessive use by livestock could negate such improvements.

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Introduction

Winter is the most critical period for mule deer (*Odocoileus hemionus*) [1/] on most ranges in the interior West (Connolly 1981). Deep snow restricts the available feeding area, severe weather (wind and cold) produces a yearly high in energy demands from the animals, and quality forage is at its yearly low.

As weather conditions worsen with the onset of winter in eastern Oregon, deer migrate from the forests of the Wallowa Mountains to the surrounding rangelands (fig. 1). Those moving south concentrate on the benchlands near the Powder River (fig. 2), in an area ranging from 1 to 10 miles wide by 40 miles long (1.6 to 16 km by 64 km), designated here as the Keating Winter Range.

[1/]Sources for scientific and common names are Garrison and others (1976) and Ingles (1965).

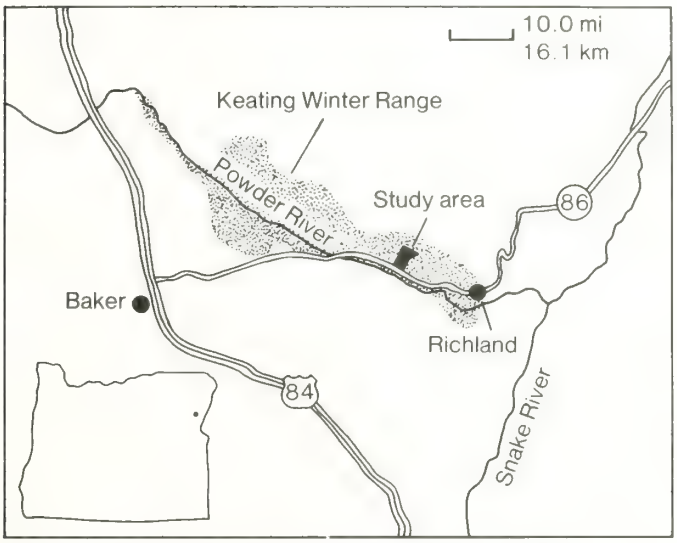

Figure 1—Location of the Keating Winter Range in eastern Oregon.

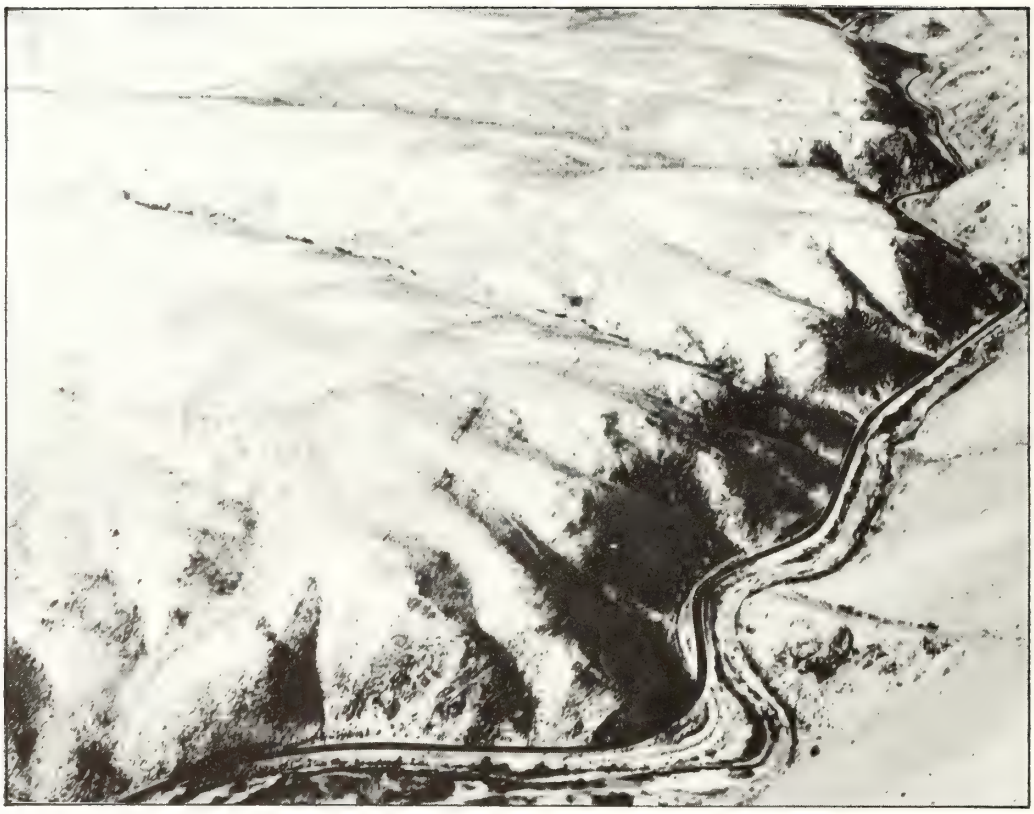

Figure 2—Aerial view of the study area on the Powder River. Note clearing of snow from the south-facing slopes.

The Keating Winter Range supports a population of mule deer that has ranged from 3,500 to 7,600 in recent years.[2/] This range generally supports deer over the winter, but with sporadic die-offs caused by severe weather and lack of adequate forage and cover. The Oregon Department of Fish and Wildlife considered the problem severe enough in the mid-1960's to develop a program of emergency feeding in winter. Although weather conditions are better in spring, the physical condition of emaciated survivors of a severe winter (fig. 3, B) will continue to deteriorate until regrowing vegetation meets their energy needs.

During the winter of 1971-72, a combination of deeper than average snow, animals prestressed by a prolonged cold spell, and restricted forage caused high mortality, estimated at 40 percent of the local herd (see footnote 2). A number of new studies were initiated in the mid-1970's to learn how to improve the carrying capacity of this range. This paper reports on (1) our study of the relationship of wintering deer to site, weather, and forage availability; and (2) the development of a predictive model of animal occupancy to aid in selection of suitable locations for forage rehabilitation and cover plantings. Other studies have reported on selecting improved varieties for range rehabilitation (Edgerton and others 1983, Geist and Edgerton 1984), and this research continues. Hilken (1983) examined in detail the energy demands of the animal and the availability of forage on the rangelands and the historical and present relationship to domestic animals.

[2/]W.R Humphreys, Oregon Department of Fish and Wildlife, Baker, Oregon, personal communication.

A

B

Figure 3--Mortality of animals on winter ranges can run high (A), as much as 40 percent of the local herd in severe winters. A survivor (B) will not regain healthy body condition until adequate forage is available (photos courtesy Oregon Fish and Wildlife Department).

Study Area

Site

The study area (fig. 4) was located along the Powder River in Baker County in northeastern Oregon and included approximately 1,600 acres (650 ha) of benchland along the river. The study area and much of the surrounding Keating Winter Range are on lands managed by the Bureau of Land Management, U.S. Department of the Interior. The study area was representative in vegetation and topography of much of the surrounding range and supported a large population of mule deer (about 75 animals), usually visible from a high elevation observation point south of the river. Elevation ranged from 2,450 to 3,400 feet (746 to 1036 m). Slopes into the 300- to 400-foot-deep (91- to 121-m) main Powder River canyon are short and steep (commonly 60 to 80 percent), whereas the gradients of the small tributary streams that run through the gentle topography of the upland benches are more moderate as they empty into the river. Side slopes into these drainages are gentle in the northern part of the study area but steepen to 60 to 80 percent near the Powder River canyon (fig. 2).

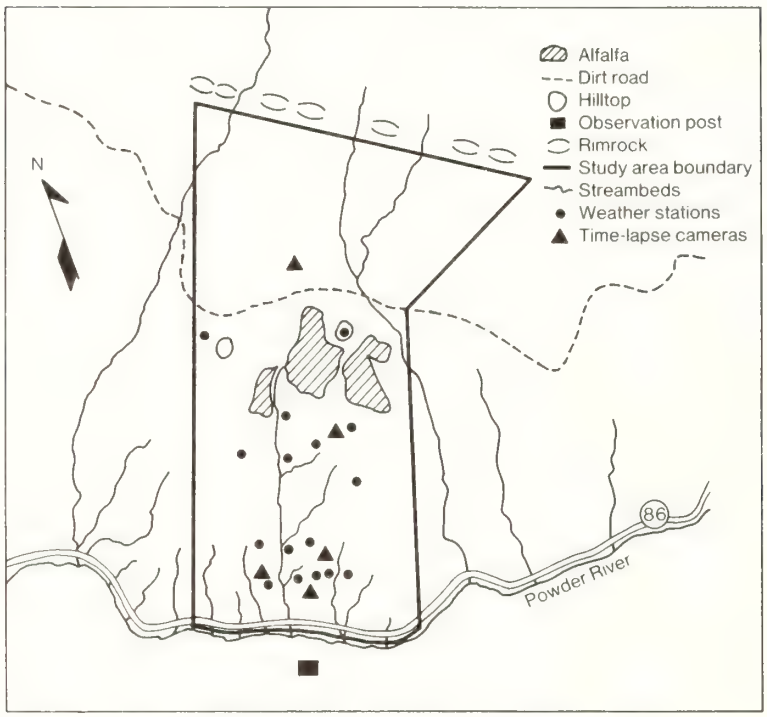

Figure 4—Map of instruments and the general study area

Vegetation

Vegetation includes big sagebrush (*Artemisia tridentata* Nutt.), bearded bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Smith), and annual grass communities with very narrow stringers of streamside riparian shrubs. A large seeding of standard crested wheatgrass (*Agropyron desertorum* Schult.) occupied the north and upper elevation portion of the study area; approximately 20 acres (8 ha) of alfalfa (*Medicago sativa* L.) had been growing in the middle of the benchland below the seeding. The lower portion of the benchland was dominated by big sagebrush, with small openings of annual grass. Through disturbance, some big sagebrush areas had been converted to rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Brit.) successional stages. At the extreme north edge of the study area, several heavily overgrazed rocky slopes supported a few small, dense stands of medusahead wildrye (*Elymus caput-medusae* L.).

Climate

Annual precipitation averages about 16 inches (40 cm) and occurs primarily during the winter. Precipitation varies with topography; lower elevation stations to the south and west are drier than highland stations to the east and north. Snow is common, accumulating to depths up to 20 inches (50 cm), with drifts rarely exceeding 40 inches (1 m).

Average daily temperatures for December through March for nearby regularly reporting stations are shown in figure 5. With the exception of Richland, mean monthly temperatures are lowest in January. Richland also is the warmest of these stations during the winter. Lengthy periods of extreme cold are infrequent, but some have lasted as long as 20 days. Minimum temperatures may drop into the -30 °F (35 °C) range locally. Minimums of -50 °F (45 °C) have been recorded at several nearby stations in eastern Oregon.

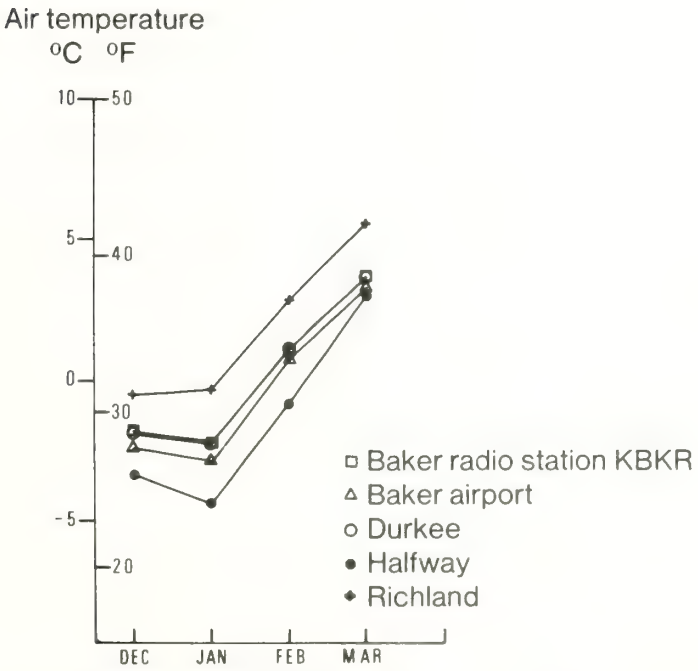

Figure 5—Average daily temperatures for nearby regularly reporting stations; based on 10-year period, December 1966 to March 1976.

Methods

During the active period of the study, 1976 to 1979, two broad classes of dynamic or changing information were collected through ocular estimates and meteorological instruments: (1) animal variables (time of day, and location and number of animals); and (2) weather variables (solar radiation, air temperature, windspeed, and wind direction). Weather data were recorded automatically at 16 locations and were complemented by general visual observation of cover and depth of snow, cloud cover, and precipitation.

Site characteristics such as aspect, slope, vegetation height, and cell coordinates were also determined.

Animal Variables

Trained observers monitored animal activity 2 days per week from the observation post south of the river. By use of binoculars and spotting scopes, animals were located accurately on large-scale maps of the study area. Animal locations were later recorded on a 100-cell, site-specific mosaic map developed from landform and vegetation descriptions of the area. Five time-lapse movie cameras were placed in strategic locations to record deer activity at 15-minute intervals during daylight hours every day, all winter, each year of the study.

Weather Variables

Sixteen weather stations were located systematically (fig. 4). These weather stations were numbered and used as visual reference points for the ocular sightings of animal activity. A summary of air temperature, windspeed, and direction was printed at 20-minute intervals. Air temperature was recorded as the average temperature for the 20-minute period. Windspeed was measured for each 0.1 mile (0.16 km) of wind travel past a station, and total wind was recorded by selected windspeed class (in m/h): 0-5, 5-10, 10-15, 15-20, 20-30, and 30+.[3/]

Fowler (1975, 1977) described the design and operation of the meteorological equipment for these weather stations in more detail. Solar radiometers were installed at 4 of the 16 weather stations. Data were coded by machine for later analysis. From the raw data on temperature and windspeed in several classes, the chill factor, average windspeed, and wind period were computed.

Snow cover was estimated in percent; snow depth was estimated and recorded in one of six classes: none, 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, or 60+ cm; cloud cover was coded: sunny, scattered clouds, broken clouds, or overcast; and precipitation was coded: none, rain, snow, or fog.

Site Characteristics

The 100 cells for the landform and vegetation mosaic were generated from large-scale aerial photos and field sampling. Vegetation, slope, and aspect were the primary criteria. Four slope classes, four aspect classes, and 11 vegetation communities were recognized. Slopes were classified as 0 to 15 percent (ridgetops), 15 to 30 percent, 30 to 60 percent, and greater than 60 percent. Aspect classes were north, east, west, and south (including canyons and ridges).

[3/]Anemometers were calibrated in English units, and all wind information is reported as m/h (miles per hour). To convert to meters per second (m/s), multiply miles per hour by 0.447.

Vegetation communities were classified as:

1. Cheatgrass brome (*Bromus tectorum* L.).
2. Alfalfa.
3. Standard crested wheatgrass.
4. Bearded bluebunch wheatgrass/antelope bitterbrush (*Purshia tridentata* (Pursh) DC.).
5. Antelope bitterbrush/bearded bluebunch wheatgrass.
6. Rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Brit.)/bearded bluebunch wheatgrass.
7. Big sagebrush/cheatgrass brome.
8. Antelope bitterbrush/needlegrass (*Stipa* sp.).
9. Big sagebrush/bearded bluebunch wheatgrass.
10. Antelope bitterbrush-rabbitbrush/bearded bluebunch wheatgrass-cheatgrass brome.
11. Rabbitbrush/bearded bluebunch wheatgrass-needlegrass.

These vegetation communities were characterized on the basis of height. Heights ranged from 0.5 foot (0.15 m) for standard crested wheatgrass to 4.25 feet (1.3 m) for the big sagebrush types.

Each cell was located by a selected central point on an X-Y grid over a map of the area. The Y direction (YDIR) represented elevation and distance from the main river valley. The X direction (XDIR) increased in value in the downstream direction of the Powder River; it had no component for elevation. Sizes of cells ranged from 0.23 acre (0.09 ha) in cell 6 to 26.66 acres (10.79 ha) in cell 85. A 180° "fisheye" lens was used to determine sky exposure at each instrument location.

Analysis

Initial analysis of the weather data for the 1976-77 winter was made by hand calculator before records were computer coded. Computer analyses were made (1) on an areawide basis (mapping of deer density in various time periods, stepwise regression of deer density as the dependent variable against site and weather variables, factor analysis on the multiyear data summaries for cells on the area); and (2) on selected individual cells (stepwise regression of animals observed vs. dynamic weather elements). Comparisons between weather elements at some sites (t-tests on means for similar time periods) and simple bivariate plots of deer density vs. other variables helped us to understand the complex interactions between site and animal use.

Results

Weather

Solar radiation.—Daily averages for solar radiation (in Langleys) at weather station 2 during 1976-77 were: December, 177; January, 152; February, 259; and March, 320.

Temperature.—Figure 6 shows the maximum and minimum temperatures for December 1976 and January 1977 at station 2, heavy plotted line, and a 3.6 °F (2 °C) departure from this station's temperature, light plotted lines. Locations of circles represent the temperature departure of the other weather stations from the station 2 measurement, and size of circle represents number of stations at a particular temperature. For example, all stations on December 4 had the same minimum

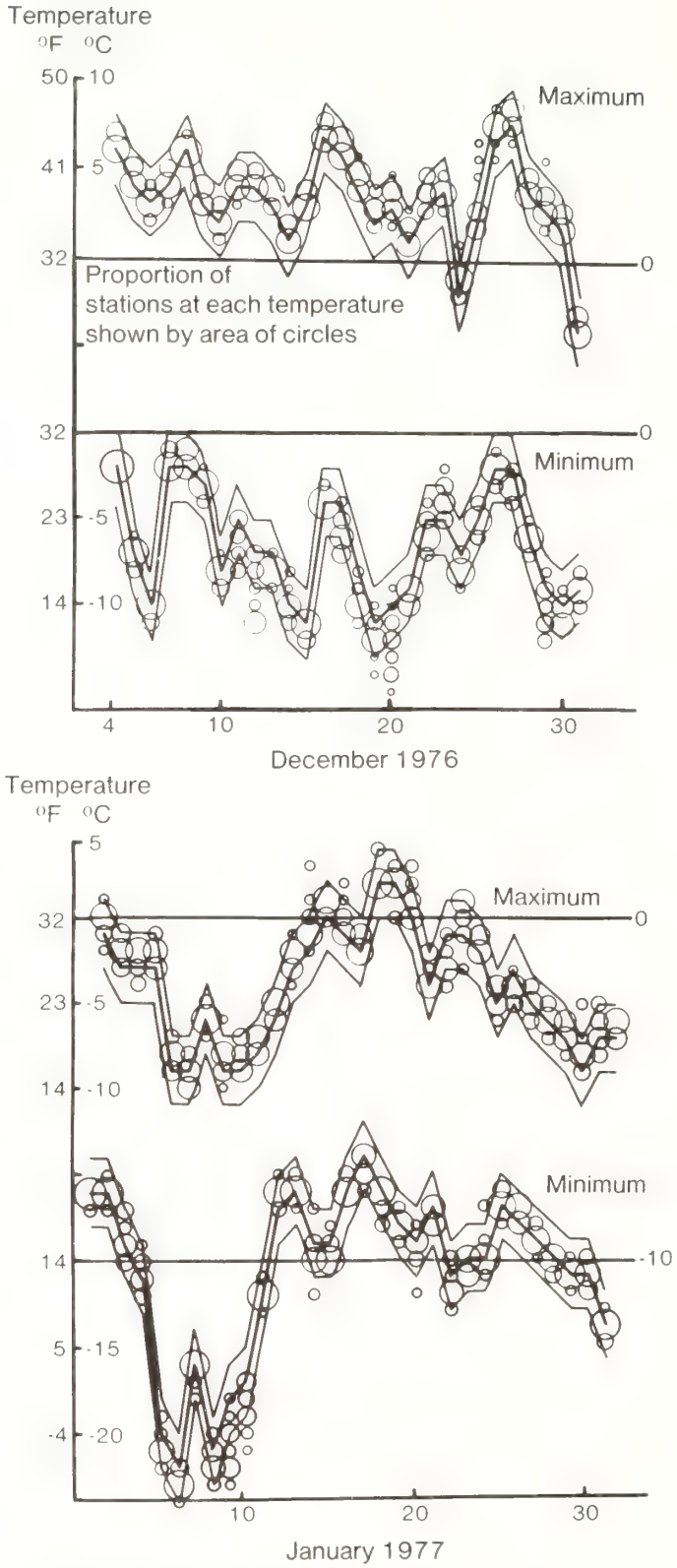

Figure 6—Temperature distribution for stations on the Keating Winter Range during December 1976 and January 1977. Station 2, heavy plotted line, was selected as a reference station. Light plotted lines are a 3.6 °F (2 °C) departure around station 2 value. Measurements from other stations are shown by location and size of circles

(2 °C) of station 2. During February, maximum temperatures of a few stations exceeded these limits. When minimum temperatures fell below the limits established, more stations exceeded the lower limit. December 12 and 20 in figure 6 are typical examples. Cold air drainage at these times established a stronger temperature gradient from warm ridgetops to the cold valley floor of the main stream channel. Temperature gradients within the area were generally quite low.

Mean daily temperatures were also computed for all data (on an hourly basis) for the winters of 1976-79. This temperature chronology is presented in the appendix. The 1977-78 winter temperatures were the mildest, and the 1978-79 winter appeared to have the longest and most severe periods of cold weather.

Wind.—Wind-measuring equipment allowed separation of data into windspeed classes. Summary information for total travel of wind at the measuring stations for the winters of 1976-77 is presented in figure 7, on the basis of all wind observed greater than 5 m/h. The effect of topography on the pattern of the isograms in this figure is well defined. As expected, exposed stations had consistently greater wind travel.

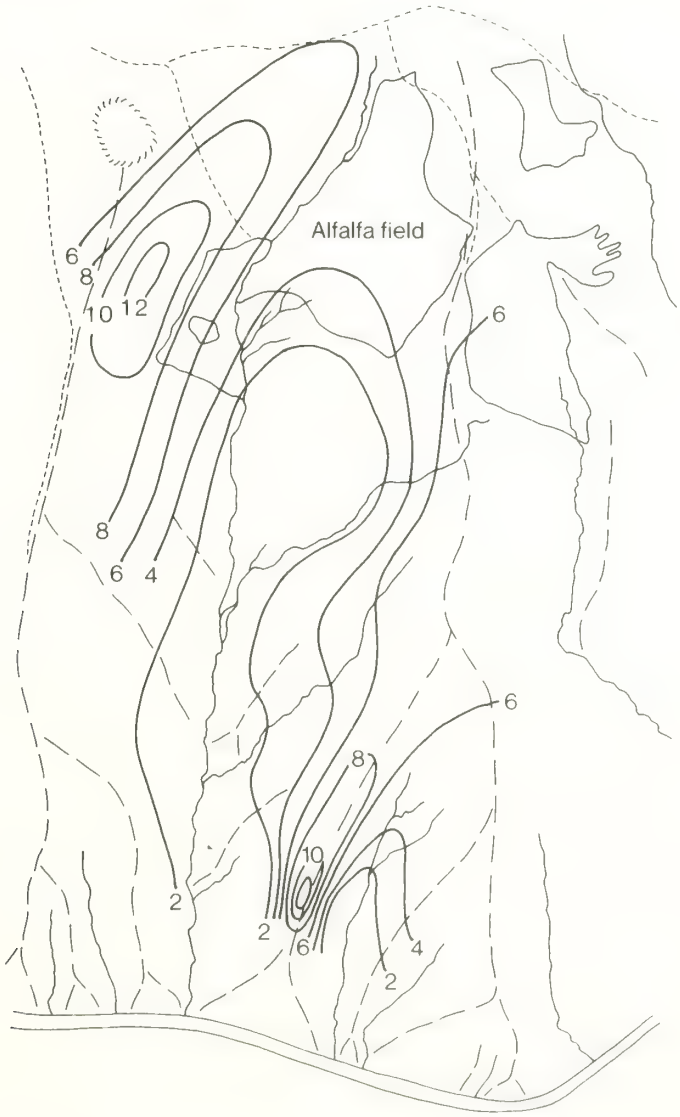

Figure 7—Total windflow (miles X 1000) at windspeeds of 5 m/h or more.

The contribution of exposure to the observed run of wind at these stations was examined. From both total wind and wind at speeds of 15 m/h and greater compared with percentage of sky observed at each station, the relationships in figures 8 and 9 were determined. In both cases, an exponential curve fitted the data best, accounting for 54 percent of the variance in wind travel in figure 8 and 62 percent in figure 9. Attempts to improve on these relationships by examining exposure in various quadrants vs. windflow were not successful.

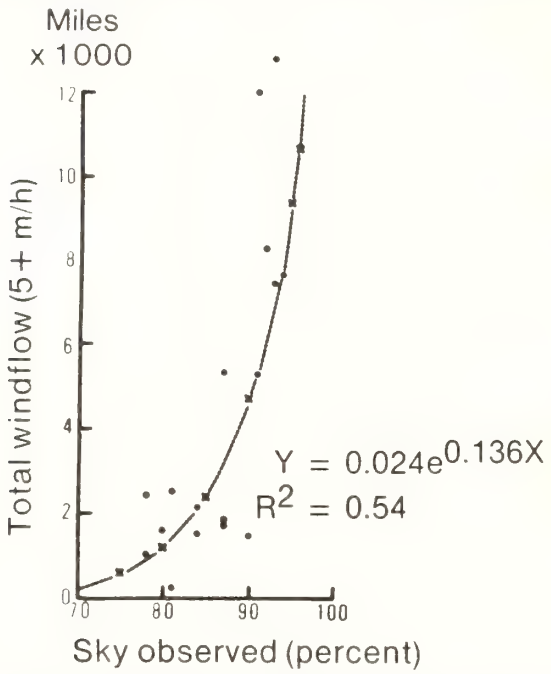

Figure 8—Regression of windflow (miles traveled at 5 m/h or more) on sky observed (percent) at instrument locations.

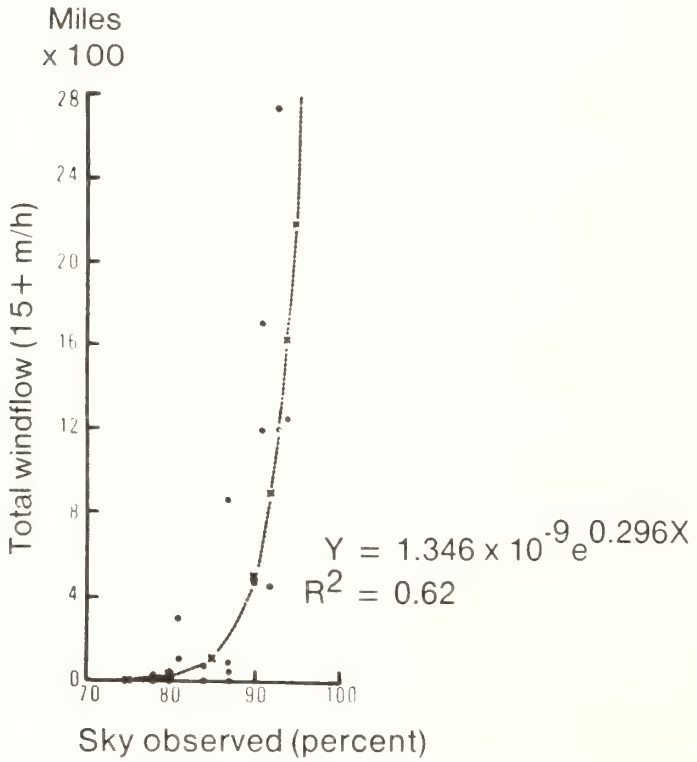

Figure 9—Regression of windflow (miles traveled at 15 m/h or more) on sky observed (percent) at instrument location.

poor for most areas. This relationship was therefore examined only for periods when speeds of 15 m/h or greater were recorded. The preferred direction for windflow during these times was generally westerly. At times, possibly associated with transition to or from cold, continental polar air from the east and more moderate maritime air masses, strong wind shifts from easterly to westerly directions or the reverse occurred. High velocity southerly or northerly winds were infrequent for the period of record in 1976-77.

Chill factor.—A critical examination of the role of wind in the determination of environmental stress on animals was not possible with the data we collected. It is sufficient to note that the heat transfer coefficient under conditions of forced ventilation increases with increase of wind velocity. The ratio of this increase is on the order of the square or cube root of wind velocity (Munn 1970). High winds coupled with low air temperatures cause rapid heat loss for poorly sheltered animals. A measure of this effect is through the various chill factor expressions (Oliver 1973), which combine temperature and wind measurement.

Chill factor expressions attempt to describe numerically the discomfort accompanying lowering temperatures and increasing wind. Reference values and accompanying sensation (on humans) are shown in the following tabulation. Values are in Kcal m^{-2} h^{-1} as provided by Oliver (1973) from various sources.

Chill factor	Sensation
2000	Exposed flesh freezes in 1 minute
1400	Exposed flesh freezes
1200-1400	Bitterly cold wind chill
1000-1200	Very cold wind chill
800-1000	Cold wind chill
600-800	Very cool wind chill

No protracted periods of high chill factor were evident in chronologies developed for 1976-79. With the exception of several days in December 1978 when average chill factors rose to 1625 over the whole area, calculated mean values were moderate for the years of record, rarely above 1200.

Snow.—Daily averages of snow depth and cover based on hourly observations at all stations during the years 1976-79 are shown in the appendix. The winter of 1978-79 had the most complete and deepest snow cover, whereas the 1977-78 winter had the least cover and depth.

Animal-Site Relationships

General distribution of animals.—Summary data for animal occupancy for the 1976-79 study period are shown in figures 10 and 11. Figure 10 shows the 4-year grand total of animals using designated cells. Grand total is the summation of daily means. Daily means are the total number in a cell divided by the number of observations of animals in a cell. Although 100 cells were defined for the study area, only 89 were observed being used by deer. The isogram analysis indicates distribution of animals was uneven over the area. Some cells along the Powder River valley bottom were not used. Because larger cells could contain more deer, animals per unit area are the basis for figure 11.

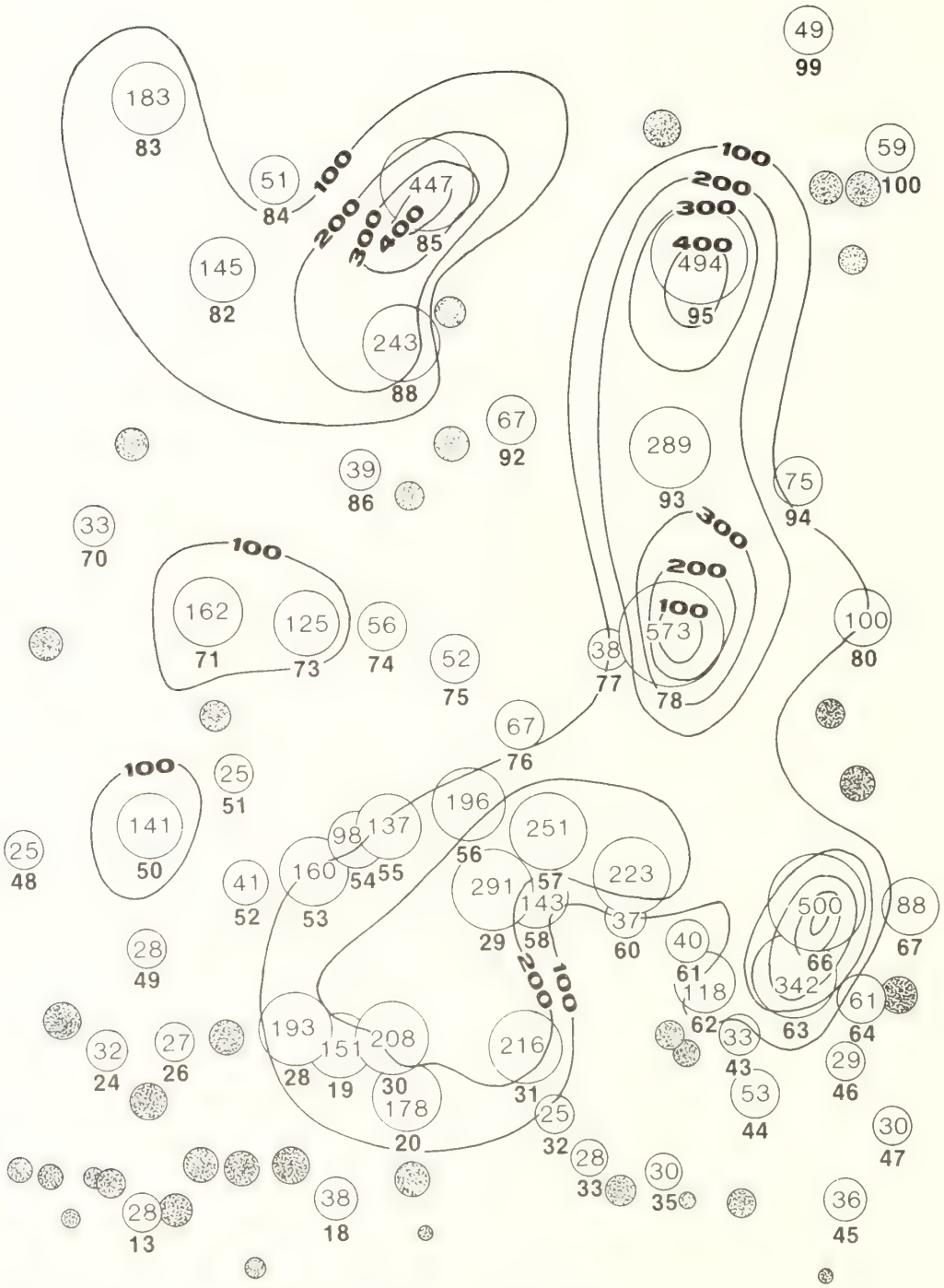

Figure 10--Plot of grand total of animals observed in each circle location. Size of circle is scaled in proportion to total number of animals (located within circles). Cell number is below circles. Cells with fewer than 25 animals are shaded and unnumbered.

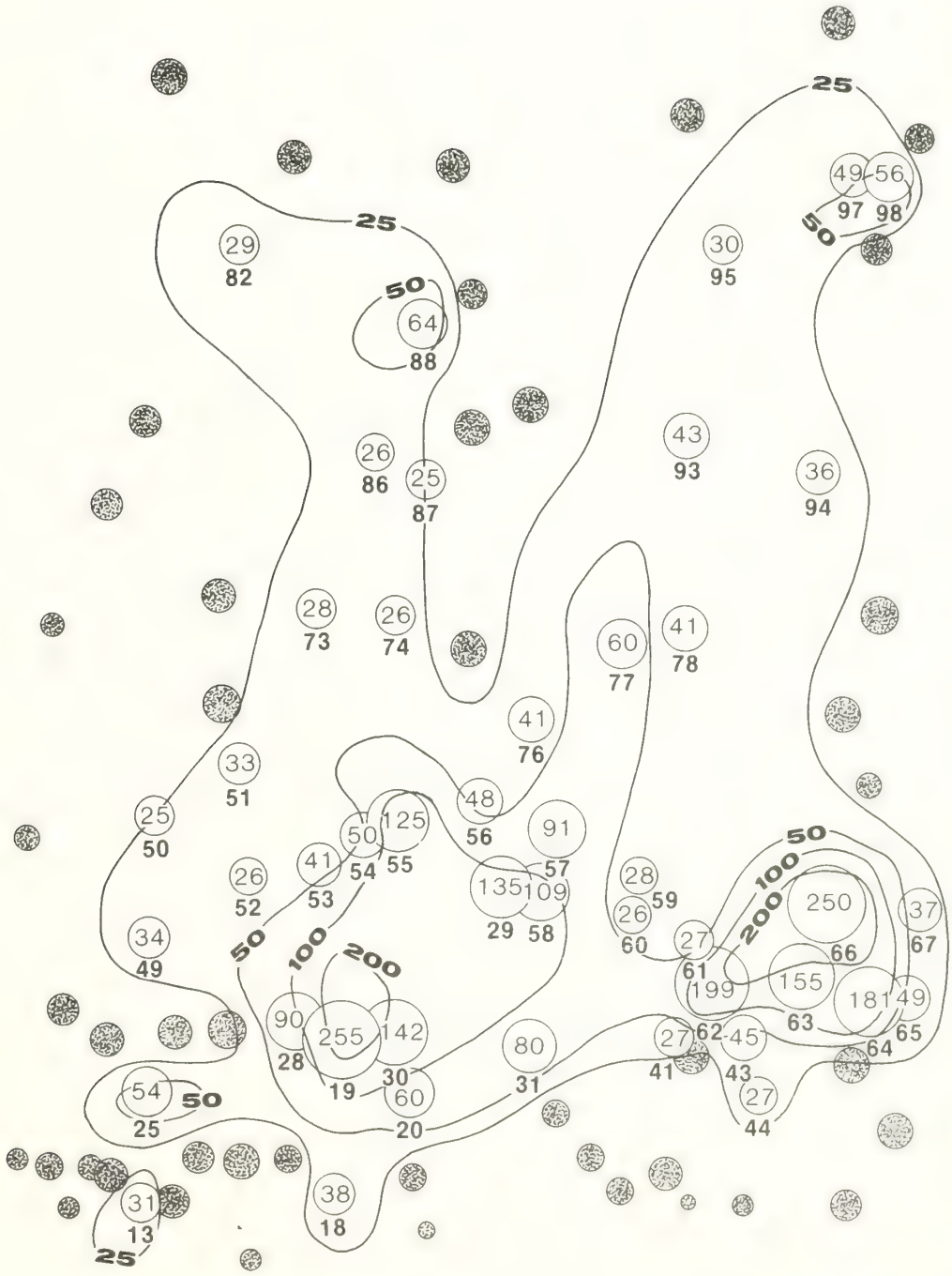

Figure 11—Plot of animals per unit area for cells

The pattern of the isograms is again evident in figure 11, with a concentration of animals on the benchlands near the valley bottoms. Animals avoided the exposed ridgetops and congregated in the main stream channel central to the study area (cells 19, 28, 30), and in a shallow headwater basin (cells 61-67). Using a per-area basis puts the large and small areas in proper perspective. Distribution of animals per unit area for each year of record was also mapped, and a similar pattern was found for each year.

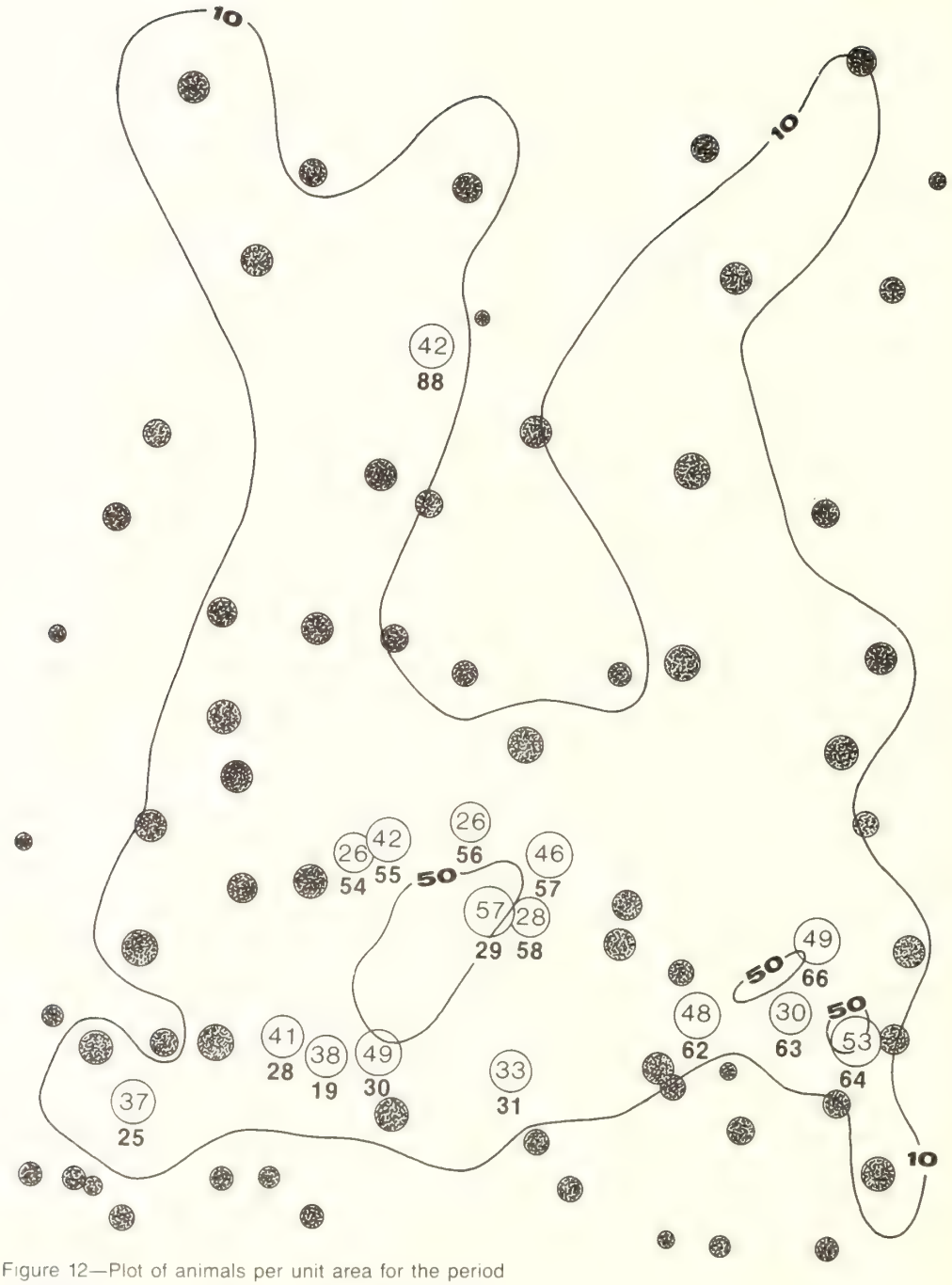

Figure 12—Plot of animals per unit area for the period 0800-1000

We anticipated a difference in animal activity corresponding to environmental changes during the day. Plots of the animals per unit areas for three periods—0800-1000, 1000-1400, and 1400-1600 hours (figs. 12 to 14)—suggested some progression of animal activity farther from the river during the 1000-1400 period. Deer were most active around cells 97 and 98 at this time. Throughout these periods animals

Figure 13—Plot of animals per unit area for the period 1000-1400.

remained concentrated in the main stream channel and around the 61-67 cell locations. Both time-lapse photography and direct observations confirmed that some deer moved away from the river to feed on the upper benches from 1000 to 1400 hours and moved back down during the 1400-1600 time period. These movements occurred during periods of mild weather and little or no snow. Downward movement of deer generally corresponded to approximately the last hour of daylight sufficient to activate cameras, approximately 1500 to 1600 hours.

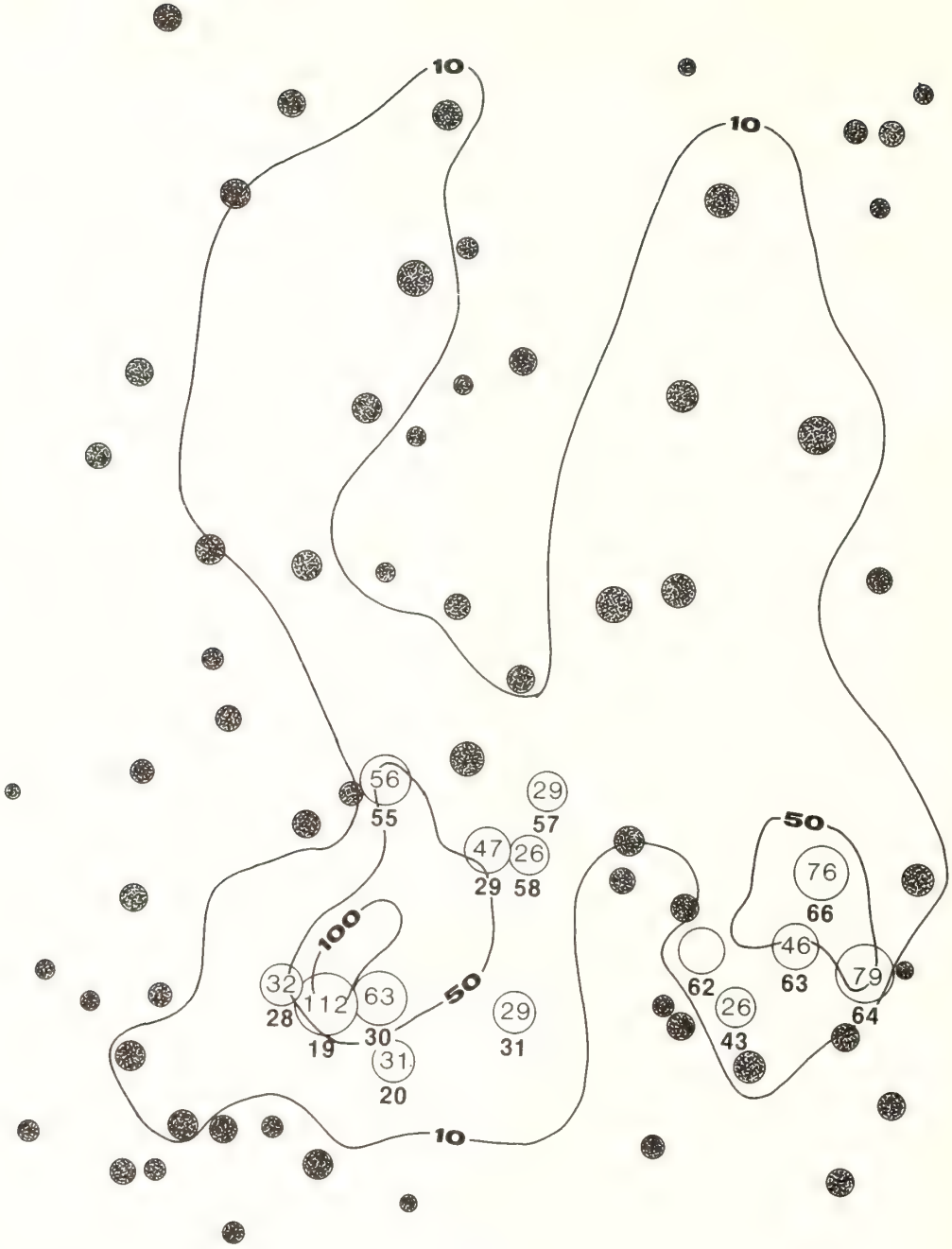

Figure 14—Plot of animals per unit area for the period 1400-1600.

preciably between time periods over the years, response of the animals to the changing weather conditions during these periods probably did. Analysis-stepwise regressions of deer against the several site and environmental factors were selected to evaluate this response. The dependent variable deer was composed of animals per unit area for each cell observed. Each observation became a case for analysis. All the current attributes about cell condition at that time (both the static and dynamic variables) were the independent variables. Analyses were for:

A. All years, December-March
   1. All times of observation (daylight)
   2. 0800-1600
   3. 0800-1000
   4. 1000-1400
   5. 1400-1600
B. All years, January and February combined
   Time periods as above.

Table 1 summarizes the information generated. Table 1 indicates multiple R^2 for the final equation for each analysis, order of inclusion in the equation and simple correlation r for first entry variable. Final equations for all analyses have a significance of $p<0.001$ and an entry level significance for variables in most cases of $p<0.001$ and only three variables as low as $p=0.005$. Only the variables that contributed to >1 percent of variance explained are included in table 1.

Table 1—Summary of stepwise regression of animals per unit of area (dependent variable, y) and cell variables

Months and hours	Analysis	R^2	Independent variables: Vegetation type	Slope class	Snow depth	Aspect	Cloud cover	Precipitation	Wind, 0-5 m/h	Wind, average m/h	Wind periods	Sky observed	Cell X location	Cell Y location	Cases	First variable r
			- Entry order into regression - -													
December-March:																
Daylight	1	0.099		2		3								1	3,717	-0.206
0800-1600	2	.093		2		3								1	2,753	-.186
0800-1000	3	.110	3	2										1	920	-.226
1000-1400	4	.396	2	1		3		7	5	4		6			1,047	.167
1400-1600	5	.159			2		3				4		5	1	786	-.233
January-February:																
Daylight	6	.093												1	2,689	-.211
0800-1600	7	.089												1	2,048	-.201
0800-1000	8	.106	2		3									1	668	-.103
1000-1400	9	.139					2			5	4		3	1	802	-.183
1400-1600	10	.119					3				2	1			578	-.249

Although we saw no major differences in the graphical analysis of number of animals in the several time periods, we speculated that there might be some differences in their relationship to local environments at certain daytimes. When data were summarized over longer periods of the day (analyses 1, 2, 6, and 7 of table 1), no influence of any of the dynamic variables (weather) was observed in the regression equations. Best predictors during these periods were static elements, notably the YDIR variable; essentially elevation or distance from the river.

For shorter time periods, all regressions still showed the static variables dominating the regression equations, YDIR being selected as best predictor in most instances. The 1000-1400 hour regression analysis (4) is notably different in both R^2 and the selection of independent variables in the final equation. In this analysis the dynamic variables of average wind, miles accumulated in the 0 to 5 m/h speed class, and precipitation type accounted for a measurable amount of the variation in animal numbers. Windspeed alone accounted for a 17-percent increase in R^2. For this time period, animal occupancy was correlated, at least in part, to the meteorological phenomena on the site. For analysis 5, period 1400-1600 hours, cloud cover and time of measurable wind (WT) were included in the regression. For the January-February analyses during the midday and afternoon, some slight influence of weather was noted.

Generally, however, static site elements—YDIR (elevation and distance from the river), slope class, aspect, and vegetation type—accounted for most of the variation in animal numbers. Weather elements were relatively ineffective predictors of animals observed per unit area.

For the data that describe cells within the study area, we might expect a degree of correlation between some of the "independent" variables. A data reduction procedure (factor analysis) (Kim 1975) is available that rearranges the data into a smaller set of components or factors. This analysis showed deer correlated strongly within only one factor. The strongest correlation of deer to any of the variables in this factor was with XDIR with an r of 0.467. As in the regression analysis above, static variables were the best predictors of animals per unit area.

Animals per cell.—We have described a series of analyses designed to relate the independent static and dynamic variables for the study area to the prediction of animals per unit area. For each cell, a subset of data describes the environmental condition relative to individual cell occupancy. An analysis could be performed for each cell based on these data. We have examined this information from only six cells selected on the basis of maximum cell usage and location: cells 29, 30, 66, 78, 85, and 95. Only dynamic variables are considered; cell constants are not identified.

Table 2 presents the results of the stepwise regression analysis for each of these cells with the included variables each accounting for more than 1 percent of the variance. The entry sequence for each variable in the final equation is shown. Simple r for the first entry variable and R^2 for the final regression equation are indicated. Note the differences in the number of animals observed, ranging from

Table 2—Summary of stepwise regression of deer per individual cell (deer per unit of area = dependent variable, y)

Cell	R^2	Independent variables: Time	Snow cover	Snow depth	Cloud cover	Wind, 0-5 m/h	Wind, 10-15 m/h	Wind, 15-20 m/h	Temperature	Wind, average m/h	First variable r	Average values for selected variables: Deer	Snow	Temperature
		Entry order into regression											Inches	°F
29	0.076		2						1		-0.187	3.56	10.5	23.9
30	.296						1			2	.450	3.27	9.5	26.8
66	.090	2		1		3					-.164	4.53	7.1	29.8
78	.066			1							-.179	6.43	4.3	31.8
85	.118	3		1	2	4					-.259	13.66	4.3	33.4
95	.351		3	1	4			5		2	-.330	16.89	1.5	36.7

3.27 animals/observation in cell 30 to 16.89 in cell 95. Except for cells 29 and 30, snow depth is the controlling variable; as snow depth increases, animal occupancy in general decreases. Cell 29 is notably different in its selected variables. The first entry variable is temperature with a negative coefficient. This indicates for this cell (and possibly for others in the valley bottoms) that animal occupancy increases with decreasing temperature. Temperature measurements in this cell on the average were 23.9 °F (-4.7 °C) compared with an average of 36.7 °F (+2.6 °C) in cell 95 during animal occupancy. Snow depth differed for these cells from an average of about 10 inches (25 cm) in cell 29 to about 1.5 inches (4 cm) in cell 95 during animal occupancy. Multiple regressions are significant ($p < 0.002$ except $p < 0.01$ for cell 66).

Discussion and Conclusions

Based on the analysis of animal activity and weather events that were observed during the 4 years of this study, these conclusions were drawn about weather in the study area and the interaction of animals and site.

1. Weather data showed that winters were relatively mild compared with the protracted periods of extremely cold weather observed in the recent past.

2. Topography significantly modified wind patterns and chill factor, the wind-and-temperature-dependent environmental variable. Slight changes in position within the area can rapidly affect exposure of an animal. Temperature appears much more conservative than wind as is evidenced by small departures from station 2. Exceptions occurred when cold air drainage into the valley bottoms increased temperature gradients.

3. Patterns of animals per unit area showed that the animals have an affinity for certain locations.

4. No major differences were observed in animal occupancy of the study area during the daytime periods. Maps of animals per unit area for various time periods showed only slight variation. Two major centers of animal concentration were observed: in the major stream channel and in a shallow headwater basin of a secondary stream. No correlation of deer per unit area and time was found.

5. The regression model showed animal per unit area related differently to static and dynamic variables during the time periods selected. Static, site-dependent variables, such as cell coordinates, aspect, and slope, were the best predictors of animals per unit area. Of these, YDIR—a variable related to cell placement, approximately equal to the distance from the main river valley—was the most consistently chosen variable in the stepwise regression equations. In the analysis for 1000-1400 hours, some dynamic weather variables were included in the final equation to raise the multiple R^2 to 0.396.

6. Factor analysis selected four factors that represented a majority of the variability in the data set. Deer, the variable of interest, was found on only one factor primarily related to static descriptors of the site.

7. Animals per cell were examined for only 6 of the possible 89 cells observed to have deer. The weather variable snow depth was the best predictor of animals per cell for most of the selected examples. Animals per cell decreased as snow depth increased. Two cells within the main canyon were observed to have a different set of predictive variables. One cell, 29, showed a negative correlation to temperature; that is, as temperature decreased, animals per cell increased. Other cells in the upper portion of the area all had positive correlations to temperature—cells filled as temperature increased. Animals appeared to be sensitive to the differences in local conditions within and between the cells.

These differences in animals per cell as related to environmental condition offer some support to the visual perception that animals moved toward the upper cells of the study area as daytime progressed (warmer temperatures) and concentrated at the lower elevations during conditions of deeper or crusted snow.

Our ability to predict animals per unit area on the study area or by implication on the more general winter range was generally poor. The single best predictor, YDIR, indicated that animals were most likely to be concentrated on the lower segments of the study area. Mapping of animal distribution showed a habitual or preferential selection of several groups of sites concentrated in the main valley bottom or in shallow headwater areas. Although some combinations of dynamic environmental factors, especially during the midday hours, influenced a movement into the upper portions of the study area, animals continued to be concentrated in these selected locations. Animals per cell showed that there was a predictable response on a cell-by-cell basis to environmental factors, but in general these factors did not modify the basic animal distributions over the area.

Two options for enhancing carrying capacity of these winter ranges appear feasible: (1) to improve the forage and protection in areas where animals are known to congregate and (2) to modify locations nearest to these areas to improve habitat and widen the zone of expected concentrated use. A third option that would attempt to further disperse the animals to the main body of the study area would be inconsistent with the observed usage of the area. Major changes in site and browse would have to be made to radically alter animals' preferences regarding these widespread sites.

Option 1 seems most feasible except that it further concentrates the animals in the sites now overused. Option 2 has more potential for dispersing use to a larger area. Forage improvement through seeding with standard or improved varieties of shrubs and grasses or management of environmental factors, such as snow depth, through snow fencing or selection of vegetation heights is possible.

Unfortunately, many of the most desirable sites for deer have poor vegetation potential because of overuse and decreased soil fertility. Only through a concentrated effort will long-term improvements be made. This effort must include careful manipulation of livestock and a stable deer herd, carefully balanced with the food supply, to prevent serious reversals in expensive habitat improvements.

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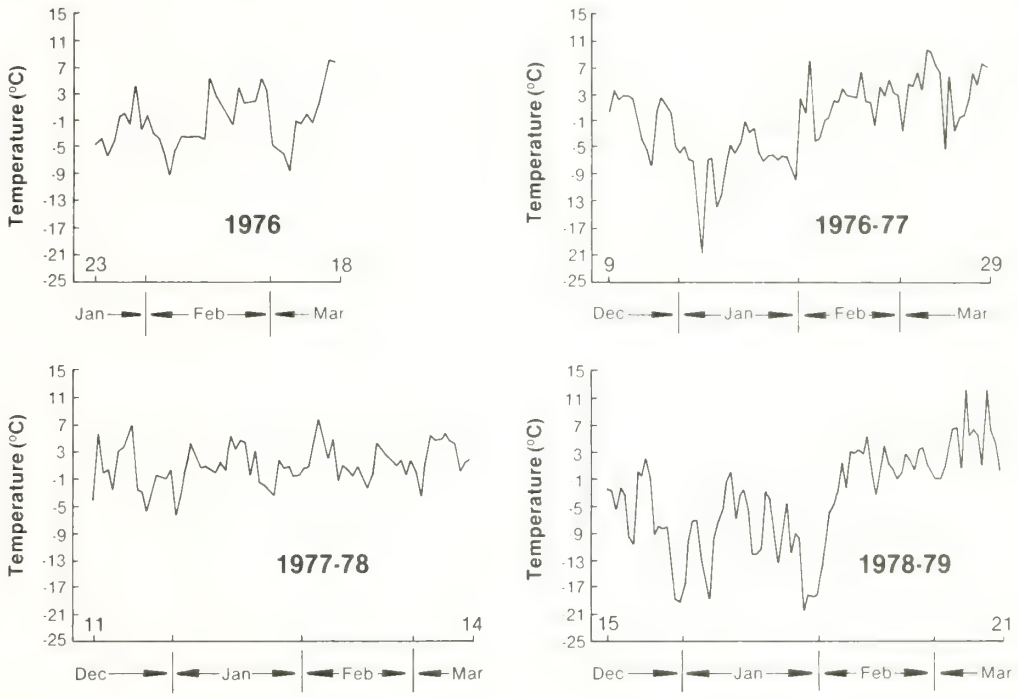
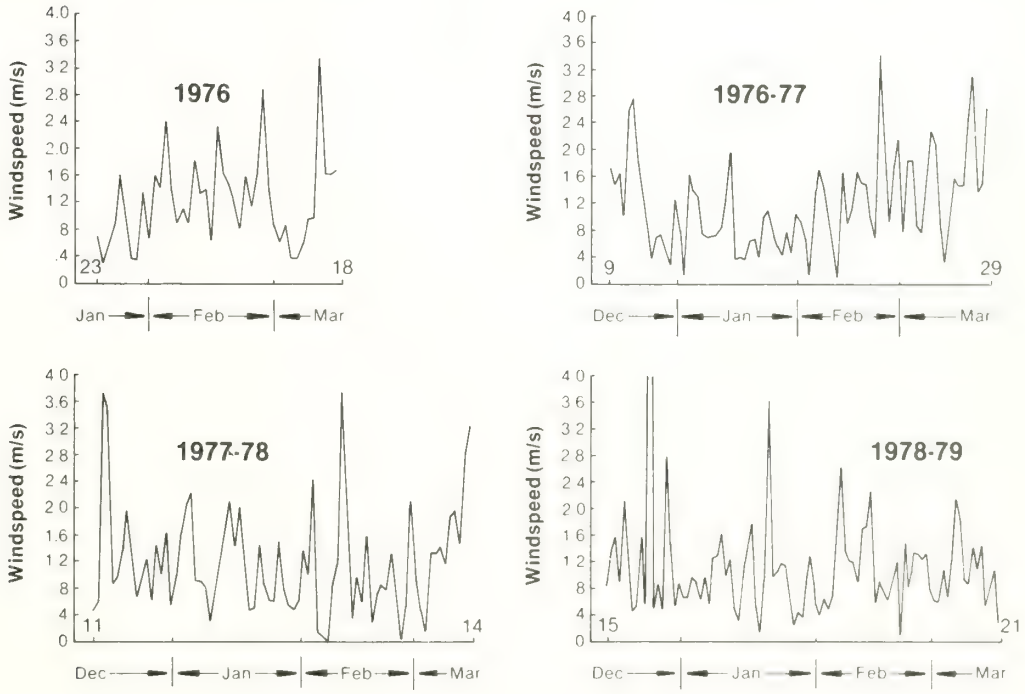
Appendix

Chill factor was computed in metric units per general use; therefore, all temperature and wind measurements (and snow depth) are also shown in metric units.

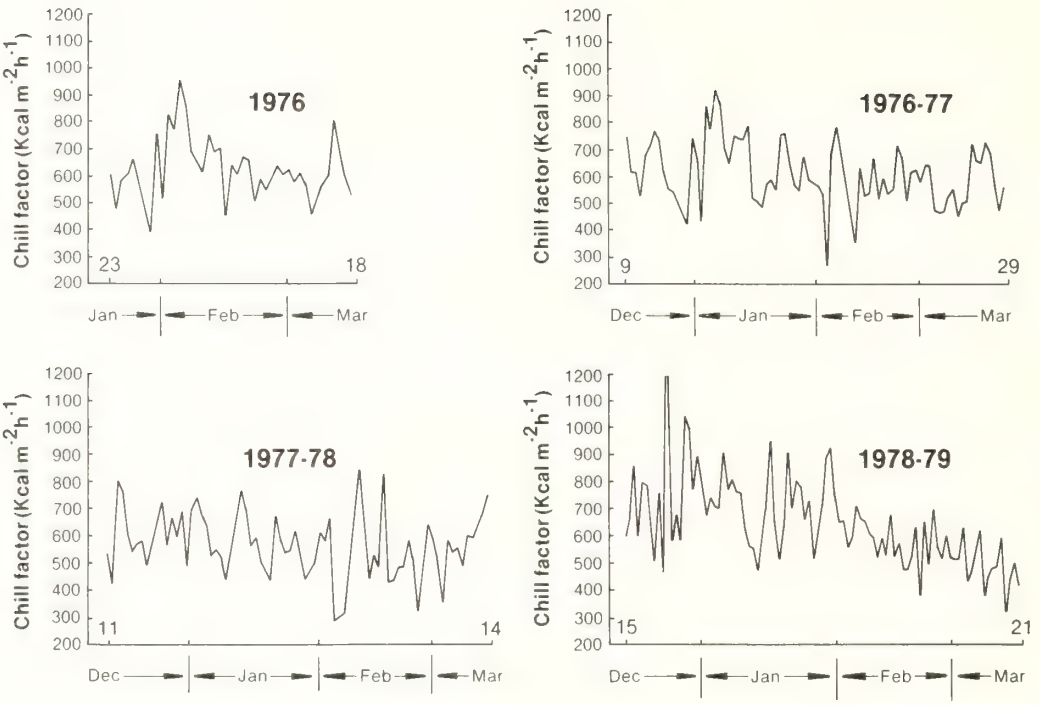
Chronology of Average Daily Air Temperature, Winter 1976-79



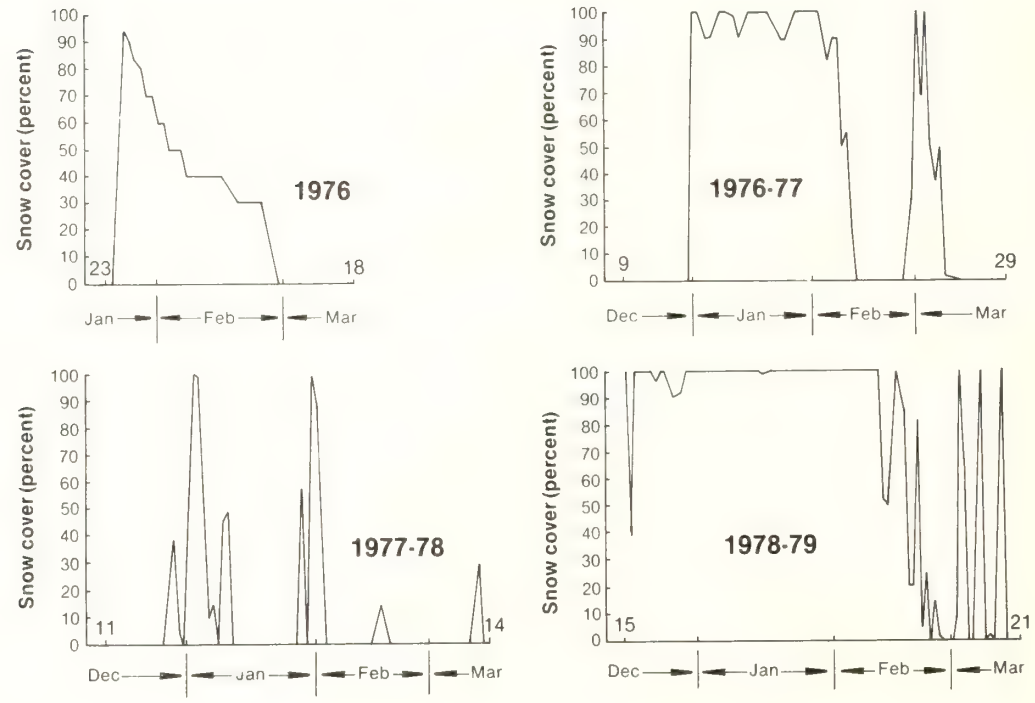
Chronology of Average Daily Windspeed, Winter 1976-79



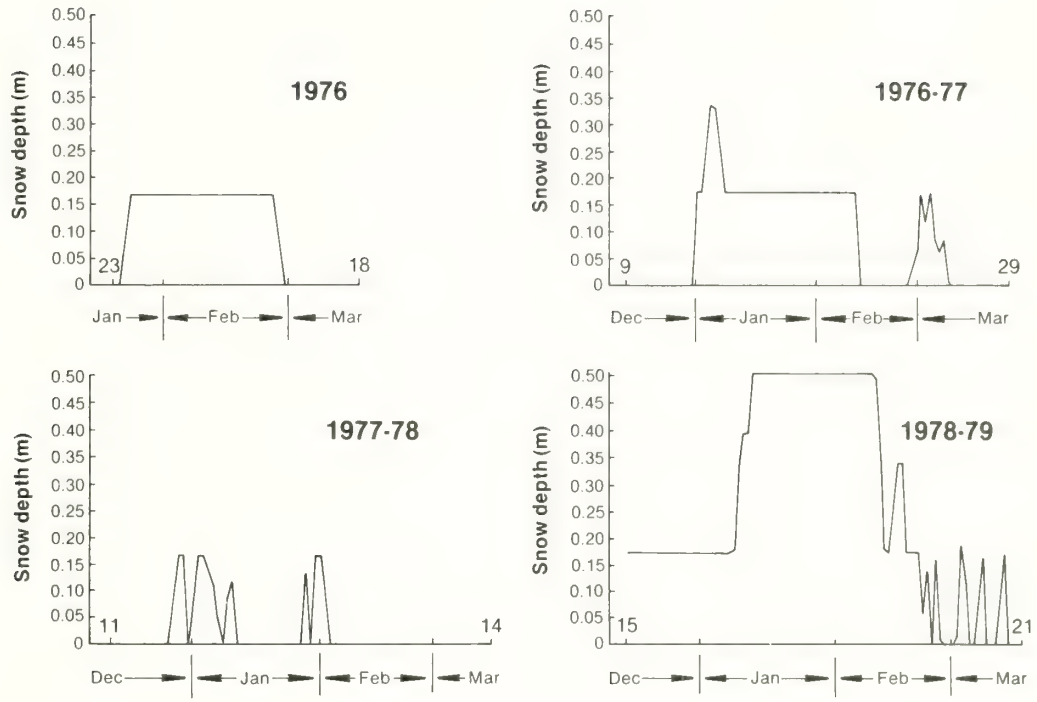
Chronology of Average Daily Chill Factor, Winter 1976-79



Chronology of Average Daily Snow Cover, Winter 1976-79



Chronology of Average Daily Snow Depth, Winter 1976-79



Fowler, W.B.; Dealy, J.E. Behavior of mule deer on the Keating Winter Range. Res. Pap. PNW-RP-373 . Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1987.** 25 p.

Observations are presented from 4 years of record, 1976 to 1979, on behavior of mule deer (*Odocoileus hemionus*) in relation to site variables on the Keating Winter Range in northeastern Oregon. Analyses of animal use per unit area showed that the preferential selection of cells was related primarily to static site variables and secondarily to weather. The most regularly selected and strongest predictive variable was distance from the valley bottom, a variable generally associated with elevation. Only during the midafternoon hours of 1400 to 1600 did dynamic weather variables contribute substantially to the variance explained by the regression equations. For individual cells, animal use was controlled by snow depth and temperature.

Keywords: Animal behavior, winter range, deer (mule).

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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Estimating the Weight of Douglas-Fir Tree Boles and Logs With an Iterative Computer Model

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CLEMSON UNIVERSITY
MAY 27 1987

Authors

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Abstract

Waddell, Dale R.; Weyermann, Dale L; Lambert, Michael B. Estimating the weight of Douglas-fir tree boles and logs with an iterative computer model. Res. Pap. PNW-RP-374. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1987.** 20 p.

A computer model that estimates the green weights of standing trees was developed and validated for old-growth Douglas-fir. The model calculates the green weight for the entire bole, for the bole to any merchantable top, and for any log length within the bole. The model was validated by estimating the bias and accuracy of an independent subsample selected from the original stand. Calculated weights were compared to actual weights as measured on truck scales. The model accurately estimated the weight of logs (less than 10 percent error) and provides an estimation technique that is expected to have application for various elements of timber management.

Keywords: Models, weight scaling (log), log weights, computer programs/programing.

Summary

The accurate estimation of bole weights in standing trees is valuable information in the planning of timber harvesting operations, particularly aerial logging. The economic viability of "heavy-lift" aerial logging, such as Heli-Stat, Cyclo-Crane, helicopters, and cable systems, will be partially dependent on accurate estimates of the payloads. We developed an iterative computer model for old-growth Douglas-fir that combines various prediction algorithms for taper and green density. Green weight can be estimated for various log lengths and merchantable top limits.

The data were collected in the Mount Hood National Forest in northwest Oregon. The model was validated with independent data by comparing predicted weights with weights measured on truck scales. Statistics on bias and accuracy are presented.

Results demonstrated acceptable error (less than 10 percent) in estimating log weights. The model analyzes the potential wood products from a stand under various logging constraints—specifically, the product characteristics (length and diameters of logs) and the weight capacity of the yarder. An example of the computer program, written in BASIC (programming language), is available from the authors.

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Introduction

There has been an increased demand in the 1980's for mathematical models that can accurately estimate the weight of logs, boles, whole trees, and forest stands. The demand has grown because of the increase in the variety of forest products and the greater use of weight scaling, and because of the critical need for accurate weight estimates in various logging systems, especially aerial logging. A maximum payload with a minimal chance of an overload is essential in aerial logging because of the high operating costs. Logs must also be bucked to maximize grade and length requirements of the mill. The purpose of this study was to develop and validate a weight prediction model for standing Douglas-fir trees (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) that could be used in planning for "heavy-lift" aerial logging. Heavy-lift is a term used to describe aerial yarders with capacities for large loads, such as the Sikorsky (S-64) Skycrane helicopter and the proposed Heli-Stat and Cyclo-Crane airships. [1/] The model also has application in other areas of forestry where estimates of tree bole, log, and crown weights are needed.

A common method of estimating the weights of trees is to develop an empirical relationship (regression equation) between weight as the dependent variable and diameter outside bark at breast height (DBHob) and tree height as the independent variables. There are two problems with this approach: (1) the model is limited to a single output, such as weight of the bole or the weight of a single log; and (2) the data used to develop the regression equations are difficult to collect. The collection of data is difficult because the harvest units may contain large timber and the units are often in remote areas. Costly equipment is needed to lift the boles, and the equipment is difficult to move to the sites. Also, a separate regression equation is required for each log length and for each merchantable top limit.

An alternative technique is to not weigh the boles but to calculate the weights from systematic measurements of diameter, bark thickness, and green density (Waddell and others 1984). These measurements provide the data necessary to develop prediction equations for taper (or volume) and green density. The green weight is computed from the product of the volume and green density predictions. This type of model can be constructed, with the aid of a computer program, to produce estimates of weights for any size bole with variable log lengths and merchantable top limits. Refer to Burkhart (1977), Cao and others (1980), Demaerschalk and Kozak (1977), and Max and Burkhart (1976) for discussions on the computational procedures and on the accuracy of various bole volume and taper equations.

The objectives of this study were (1) to develop a model for Douglas-fir trees that would estimate weights for the entire bole, for the bole to various merchantability limits, and for logs with various lengths; and (2) to evaluate the accuracy of the model by comparing estimated weights with actual weights from an independent subsample from the same area (harvest unit).

[1/]Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Methods

Study Area

The study area was in the Clackamas Ranger District, Mount Hood National Forest, in northwest Oregon. The area was 14 acres and contained only old-growth Douglas-fir. The 280-year-old stand was partially cut in 1973 as a shelterwood silviculture treatment. [2/]

Sampling

All trees within the area were measured for DBHob [3/] with a diameter tape and total height [4/] with a clinometer. A total of 185 trees were tagged and assigned a sequential number. The DBHob measurements were entered into a computer and were sorted into four diameter classes (11-20 inches, 21-30 inches, 31-40 inches, and greater than 41 inches). A stratified random selection of 18 sample trees was made by proportionally allocating the number of samples for each diameter class based on the number of trees contained (population stratum) in each class (Freese 1962).

Measuring Sample Trees

The 18 sample trees were felled and each tree was measured for total height. The diameter of the butt end of the bole was measured by averaging the longest and shortest diameter (to the nearest 0.1 inch) for both inside and outside bark. The bole was then marked at 3-foot intervals up to a 6-inch top (diameter outside bark (dob)). At every 3-foot interval, the dob was measured with calipers. Bark thickness was also measured with a bark thickness gauge in three perpendicular locations around the circumference of the bole. At every 6-foot interval, starting at 3 feet from the base of the bole, three increment cores were extracted from the wood (perpendicular locations). The green density of each core was measured with a Bergstrom xylodensimeter (Waddell and others 1984), and the mean of the three green densities was calculated. This resulted in one green density value for every 6-feet of tree bole. Figure 1 illustrates how the data were collected from each sample tree.

Weighing Validation Logs

About one-half of the population trees (93) were felled and bucked into various log lengths. Each log length was measured, and the log was tagged for identification. The logs were then yarded (using horses) to a landing and weighed with a self-loading log truck and platform scales. A total of 326 logs were weighed.

[2/]The stand was selectively harvested in 1973 and then underburned to control competing vegetation.

[3/]Diameter outside bark is measured at 4½ feet on the uphill side of the tree.

[4/]Total height is measured to the tip of the crown.

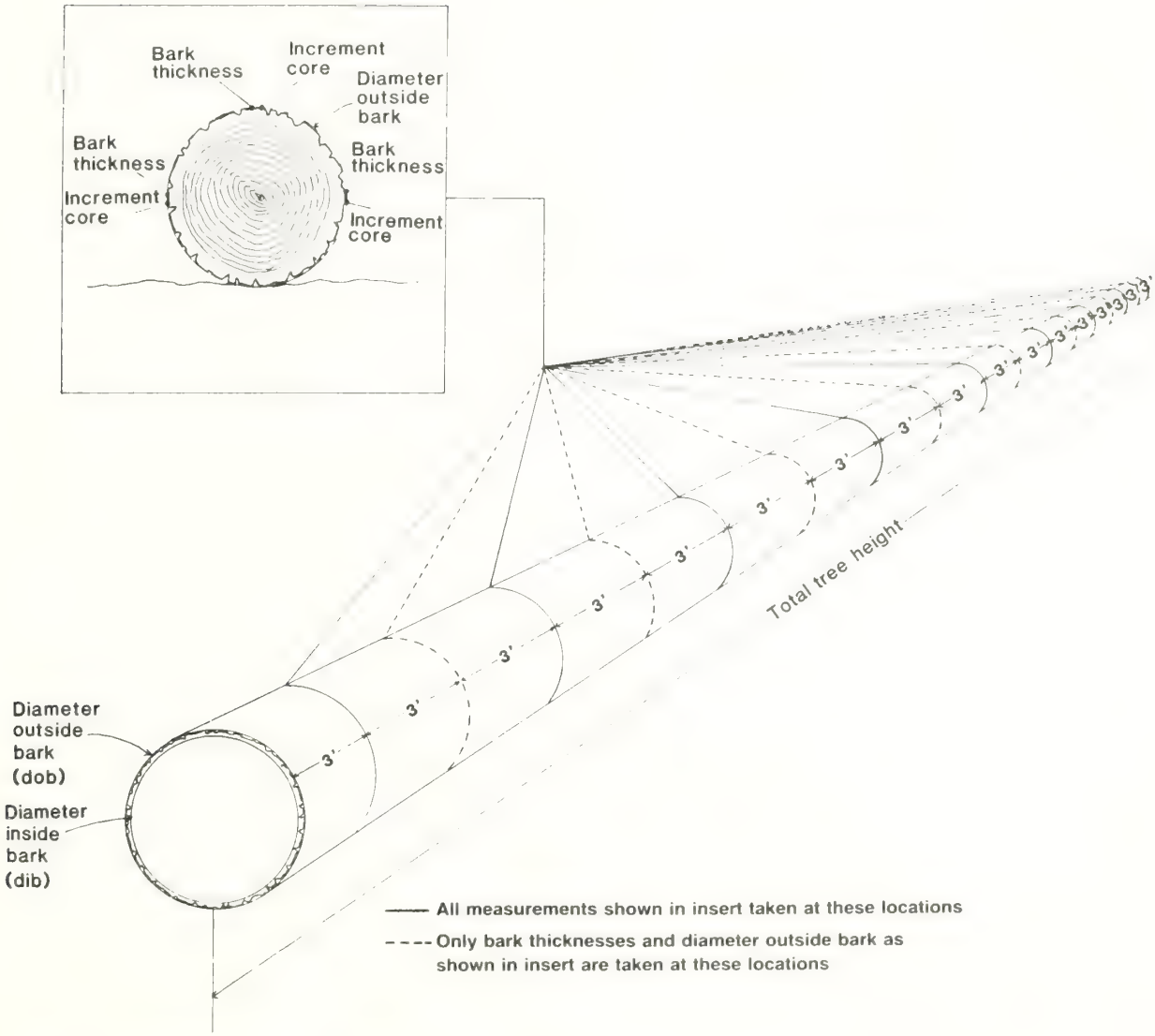

Bark thickness
Increment core
Diameter outside bark
Bark thickness
Bark thickness
Increment core
Increment core
3'
Total tree height
Diameter outside bark (dob)
Diameter inside bark (dib)
All measurements shown in insert taken at these locations
Only bark thicknesses and diameter outside bark as shown in insert are taken at these locations

Figure 1—The type and location of information collected from the boles of each sample tree.

Analysis and Description of the Computer Model

Notation

The following is a list of variables used in the predictive equations and in the computer program.

a, b_i	= regression coefficients estimated from sample data.
ob, ib	= outside or inside bark.
DBHob, DBHib	= diameter in inches at 4½ feet.
Rob, Rib	= diameter ratios (dob÷DBHob and dib÷DBHib, both as functions of relative height in the bole).
relht	= relative height (height at a selected position in the bole÷total height).
Doble, Dible	= diameter outside and inside bark in inches at the large end of the bole segment.
Dobse, Dibse	= diameter in inches at the small end of the bole segment.
ds(ob), ds(ib)	= diameter in inches at the end of the bole (stump cut).
gden	= density of the green wood (pounds per cubic foot).
brkden	= density of the green bark (pounds per cubic foot).
Vob, Vib	= volume (cubic feet).
C	= pi÷(4x144); a constant that, when multiplied by the diameter in inches, results in the basal area of the cross-sectional area (square feet).
L	= length of a log.
lseg	= iteration or segment length for computing volume and weight (computer program).
totht	= total height of the tree.
MT	= merchantable top limit.

Model Development

The iterative computer model combines a calculated volume with a predicted green density for small segments of the tree bole; the model begins at the base and ends at the top of the bole. This is accomplished with six types of equations or algorithms:

Type A. Equation for predicting the inside bark diameter at DBH:

$$DBHib = a+b(DBHob) .$$

Type B. Taper equations for predicting bole diameters at various heights:

$$Rob \text{ and } Rib = a+b_1(relht)+b_2(relht)^2+b_3(relht)^3+b_4(relht)^4+b_5(relht)^5 .$$

Type C. Taper equations for predicting diameters at the end of the butt log:

$$ds(ob) = a+b(DBHob), \text{ and } ds(ib) = a+b(DBHib) .$$

Type D. Smalian's volume formula:

$$Vob = CL(Dob^2 + dob^2)/2 , \text{ and}$$
$$Vib = CL(Dib^2 + dib^2)/2 .$$

Type E. Butt log formula (Bruce 1982):

$$Vob = CL(0.25(ds(ob))^2 + 0.75(DBHob)^2) \text{ , and } Vib = CL(0.25(ds(ib))^2 + 0.75(DBHib)^2)$$

Type F. Equation for predicting the green density of the wood:

$$gden = a + b_1(relht) + b_2(relht)^2 + b_3(relht)^3 \text{ .}$$

Linear regression techniques were employed to fit predictive equations (A, B, C, and F) to the measurements taken on the sample trees. Type A equations convert the measured DBHob to a predicted DBHib. Type B equations are taper equations that describe the profile of the tree (ob and ib) (fig. 2). We elected to use a taper equation and to calculate the volume iteratively within a computer program rather than use a volume ratio or direct integration of volume. The former approach uses "user interactive inputs" that produce for each standing tree a greater diversity of output, such as diameter, volume, and weight, for a variety of log lengths and merchantable top diameters. Both type B equations were conditioned such that when the relative height equals zero, the diameter ratio (Rob and Rib) is one, and when the relative height equals one, the diameter ratio is zero (Demaerschalk and Kozak 1977). Relative height for the diameter ratios begins at DBHob. Type C equations predict the diameters at the end of the bole (stump cut) from DBH. Type D equations are from Smalian's volume formula (Dilworth 1981), which was combined with the type B equations to provide estimates of volume for segments of the bole above DBH (ob and ib). The type E equations are from Bruce's butt log volume formula (Bruce 1982), which was combined with type C equations to provide estimates of volume for the lower bole (below DBH, ob and ib). Type F equations predict the density of green wood for various increments of relative height (fig. 3). Relative height begins at the stump in the equation for predicting green density .

There are two different relative heights computed for a given bole segment (relht1 for green density starting at the stump and relht2 for diameter ratio functions starting at DBH). Each relative height is calculated differently within the iterative process so that the functional solutions for green density and diameter ratio are matched with the appropriate bole segment.

A computer program was created to read the stand variables (input), to organize the calculations (processing) that determine bole dimensions (such as diameter, volume, density, and weight) from the equations discussed previously, to create loops to increment the calculations, and to provide mechanisms for the storage and output of summary information. The program was developed in sections called subroutines.

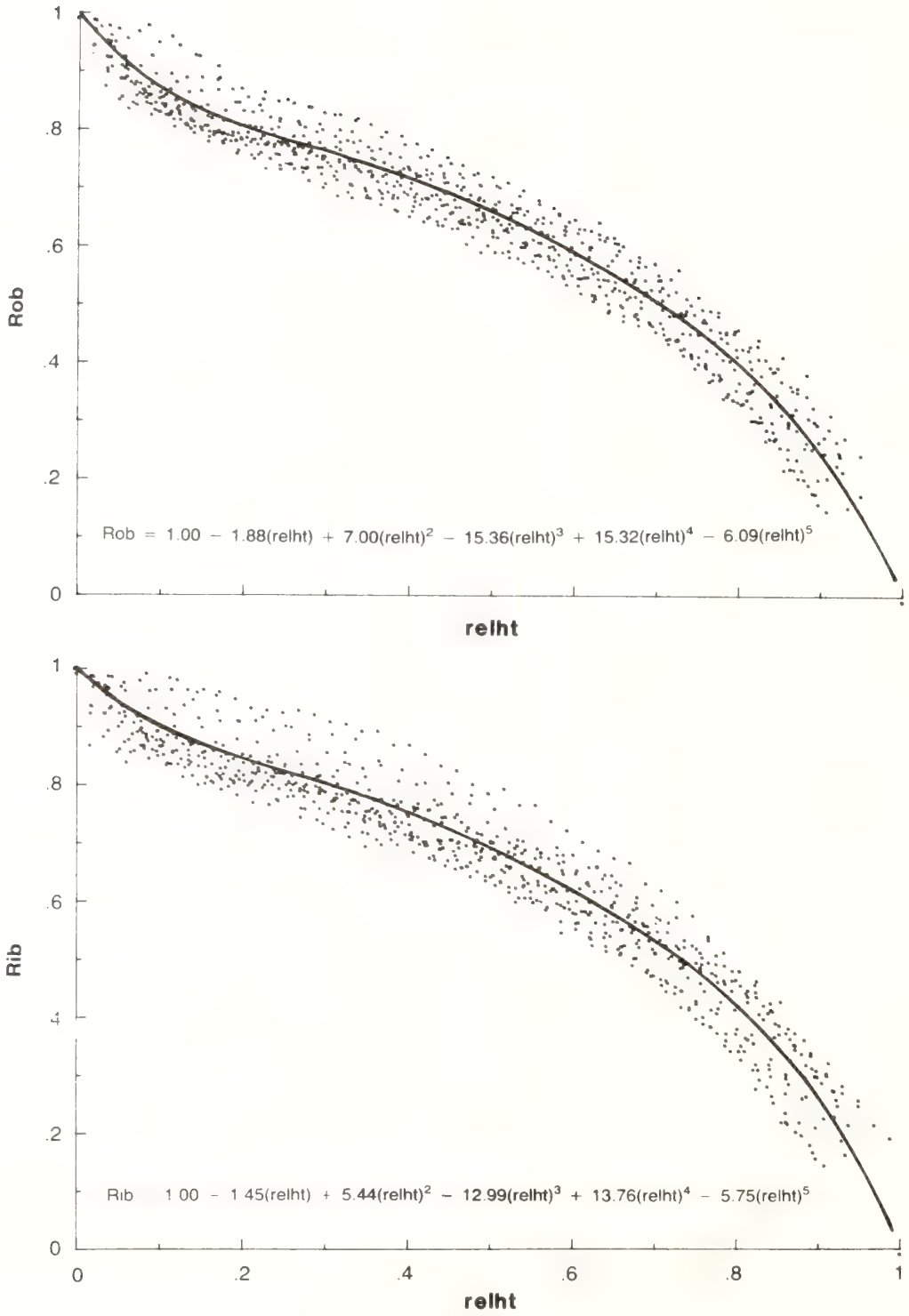


Figure 2—Equations for predicting the outside and inside bark diameters from relative height. Rob and Rib are the diameter ratios for outside and inside bark respectively; relht is the relative height

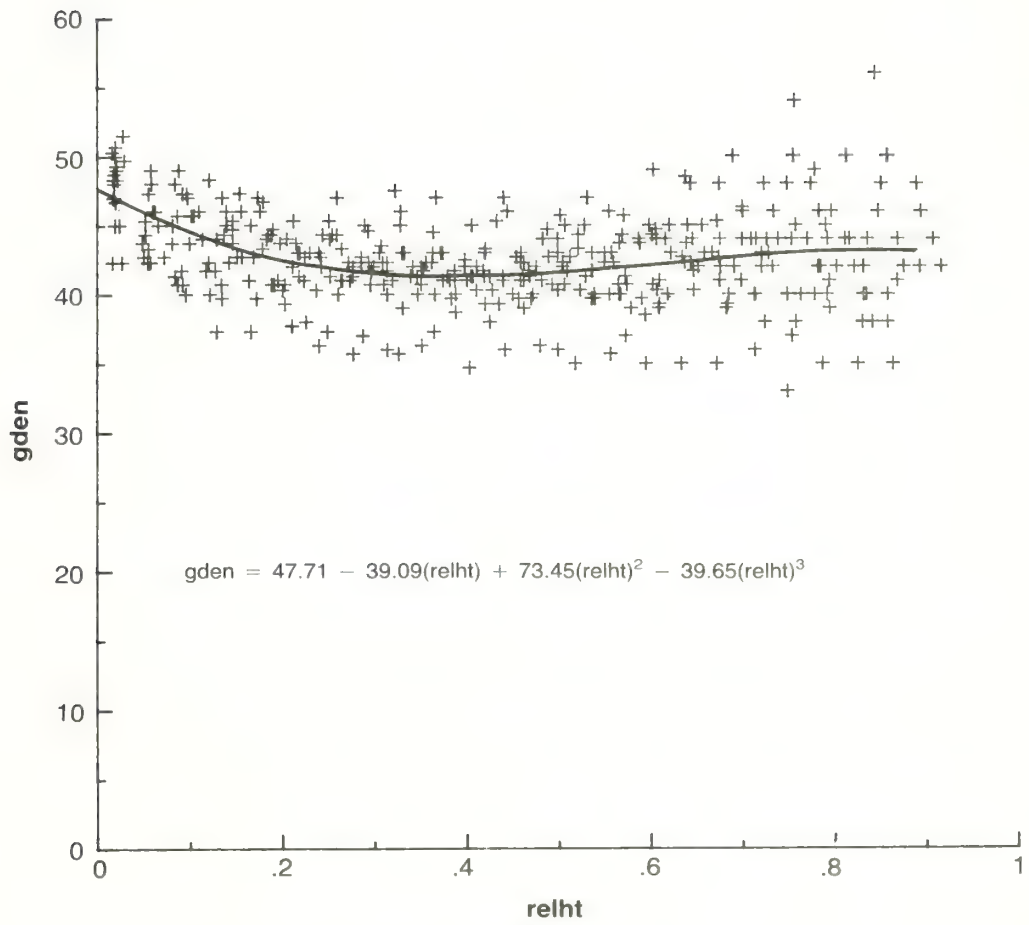


Figure 3—Equation for predicting the green density of wood. Gden is green density measured with the Bergstrom xylodensimeter, and relht is the relative height.

Subroutine that calculates the weight of the bole—Stand inventory data in the form of a species code, DBHob, and total height measurements are entered into a file. The file is then read by the iterative program. Stump height, bark density, and the number of iterations are entered by the user in response to prompts in the program (fig. 4). The subroutine begins by calculating the weight of the bole segment from the stump to DBHob (process one). This is accomplished by combining equations (A), (C), (E), and (F) (table 1).

The bole of the tree above DBHob is then divided into many small segments (iterations), and calculations of each segment's weight take place using equations (A), (B), (D), and (F) (process two) (table 2). Data arrays are created from the equations as the program moves incrementally from DBHob to the top of the tree and stores the weights, cumlative lengths, and diameters. Each tree in the data file will go through the same iterative process. The user controls the number of iterations, which dictate the size and number of segments considered for each tree. The greater the number of iterations, the smaller the bole segment, which theoretically reduces the error attributed to the calculation of volume.

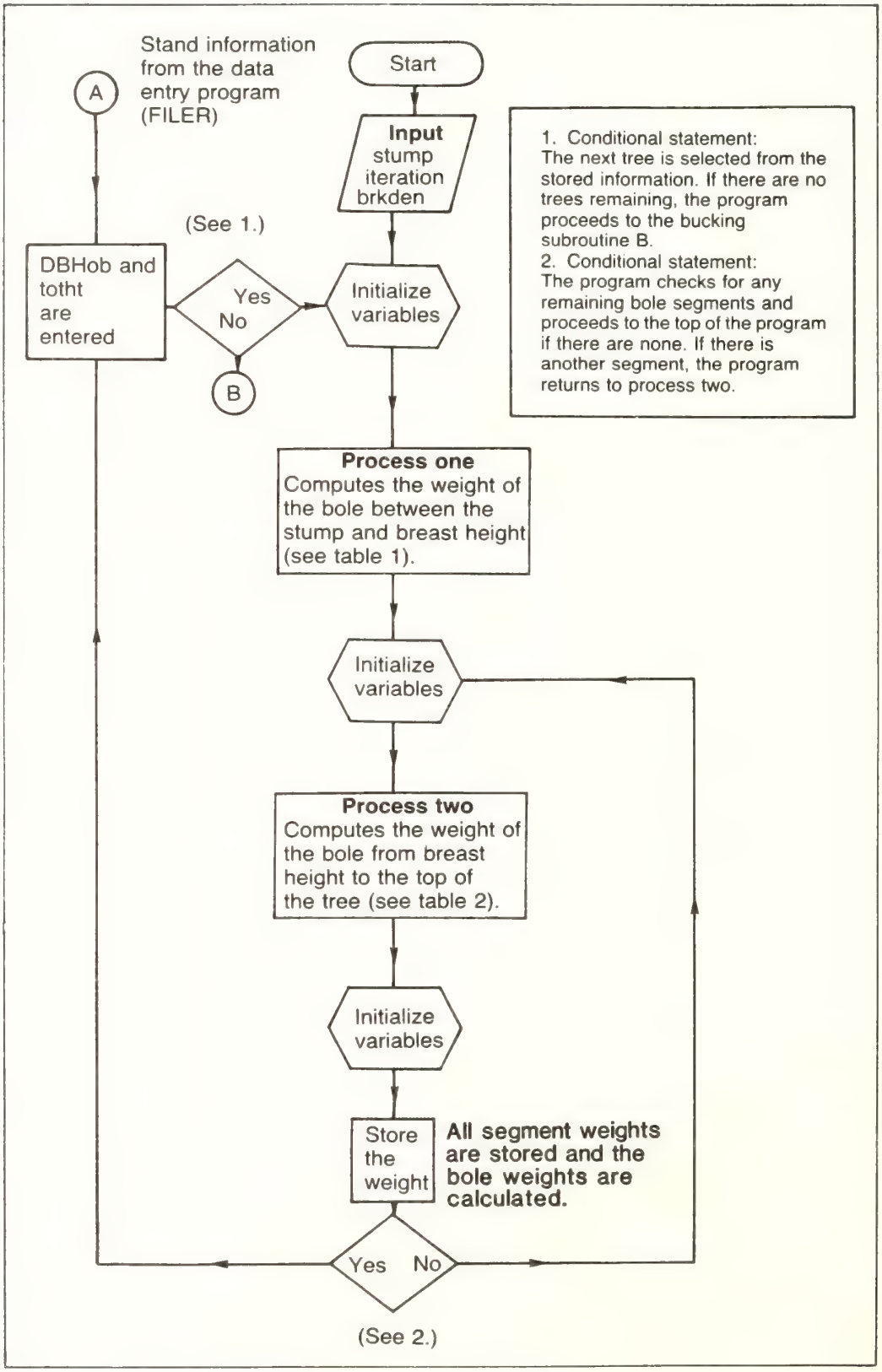

Stand information from the data entry program (FILER)
A
Start
Input stump iteration brkden
(See 1.)
DBHob and totht are entered
Yes
No
Initialize variables
B
1. Conditional statement:
The next tree is selected from the stored information. If there are no trees remaining, the program proceeds to the bucking subroutine B.
2. Conditional statement:
The program checks for any remaining bole segments and proceeds to the top of the program if there are none. If there is another segment, the program returns to process two.
Process one
Computes the weight of the bole between the stump and breast height (see table 1).
Initialize variables
Process two
Computes the weight of the bole from breast height to the top of the tree (see table 2).
Initialize variables
Store the weight
All segment weights are stored and the bole weights are calculated.
Yes
No
(See 2.)

Figure 4—Flowchart of the subroutine that estimates the weight of tree boles.

Table 1—Process one: calculations required to estimate the weight of each bole from the stump to breast height

Step number	Criterion variable	Input variable 1/	Algorithm
1	[DBHib]	DBHob	$a+b_1(DBHob)$
2	[ds(ob)]	DBHob	$a+b_1(DBHob)$
3	[ds(ib)]	[[DBHib]]	$a+b_1(DBHib)$
4	[relht1]	stump, totht	$(4.5-stump)\div(totht-stump)$
5	[gden]	[[relht1]]	$a+b_1(relht1)+b_2(relht1)^2+b_3(relht1)^3$
6	[Vob]	DBHob, dsob, stump	$(C)(4.5-stump)(0.25\ (ds(ob))^2+0.75\ (DBHob)^2)$
7	[Vib]	[[DBHib, ds(ib)]], stump	$(C)(4.5-stump)(0.25\ (ds(ib))^2+0.75\ (DBHib)^2)$
8	[Vbark]	[[Vib, Vob]]	Vob-Vib
9	[weight]	brkden, [[gden, Vbark, Vib]]	(Vib)(gden)+(Vbark)(brkden)

1/ Double brackets indicate that the input variables have been calculated in a previous step.

Table 2—Process two: calculations required to estimate the weight of a single bole segment above breast height

Step number	Criterion variable	Input variables 1/	Algorithm
1	[lseg]	totht, iterations	$(totht-4.5)\div(iterations)$
2	[relht1]	stump, totht,[[lseg]]	$(lseg+(4.5-stump)\div(totht-stump))$
3	[relht2]	stump, totht,[[lseg]]	$(lseg+(4.5-stump)\div(totht-4.5))$
4	[Rob]	[[relht2]]	$a+b_1(relht2)+b_2(relht2)^2+b_3(relht2)^3+b_4(relht2)^4+b_5(relht2)^5$
5	[Dobse]	DBHob, [[Rob]]	(DBHob)(Rob)
6	[Rib]	[[relht2]]	$a+b_1(relht2)+b_2(relht2)^2+b_3(relht2)^3+b_4(relht2)^4+b_5(relht2)^5$
7	[Dibse]	[[DBHib, Rib]]	(DBHib)(Rib)
8	[Vib]	[[Dible, lseg, Dibse]]	$(C)(lseg)((Dible)^2+(Dibse)^2\div 2)$
9	[Vob]	[[Doble, lseg, Dobse]]	$(C)(lseg)((Doble)^2+(Dobse)^2\div 2)$
10	[Vbark]	[[Vob, Vib]]	Vob-Vib
11	[Wbark]	brkden, [[Vbark]]	(Vbark)(brkden)
12	[gden]	[[relht1]]	$a+b_1(relht1)+b_2(relht1)^2+b_3(relht1)^3$
13	[weight] 2/	[[Vib, Wbark, gden]]	(Vib)(gden)+Wbark

1/ Double brackets indicate that the input variables have been calculated in a previous step.

2/ The weights are stored in arrays by diameter class and species. The arrays are accessed by the bucking subroutine at a later stage in the program.

Subroutine that simulates the bucking of the bole—The next subroutine considers the weight, length, and diameter arrays processed previously and partitions each tree into log weights, log lengths, and log-end diameters (fig. 5). The user enters the target weight for the yarder in pounds. The target weight is a value under the absolute capacity of the yarding machine. The target will become a constraint criterion for producing long logs. Multiple runs of the program can be made using varying target weights to determine the approximate target weight that is low enough to avoid excessive stress on the equipment and to avoid "aborts" (aborts in aerial logging are loads that are to heavy to lift or must be dropped before reaching the landing). The target weight must also be high enough to allow efficient use of the yarding equipment and to produce maximum log lengths. For example, in heavy-lift aircraft, such as the Skycrane S-64 helicopter, the absolute capacity of the machine is about 20,000 pounds, but because of fuel and environmental conditions, the real capacity may fall below 16,000 pounds. A safe target might be 15,000 pounds.

The next step in the program is to enter the merchantable top diameter. Typically 4-, 6-, or 8-inch tops are considered, depending on the specifications of the timber sale. The next set of entries is the preferred bucking lengths. The program will select from three preferred lengths; the longest bucking length is the highest preference. A minimum length for the butt logs and a minimum length for all other logs (minimum merchantable log) are also entered.

The program accumulates the weights, lengths, and diameters of small sections of the bole from the base upward until either the accumulated length exceeds the longest preferred length or the weight is greater than the target weight. If the weight is greater than the target and the length is less than the preferred length, the second preferred length is bucked, and a new weight is compared to the target weight. This process continues until all trees are bucked into the appropriate lengths, and weights are predicted for each log. If the weight of the butt log is above the target weight and the length of the butt log is below the minimum length entered, the log is ripped lengthwise and each pair of new logs is compared to the target weight. Ripping logs with a falling saw is a common and expensive activity in aerial logging and often occurs when there is a combination of low lift (yarder) capacity and large timber.

All other logs falling below the third preferred length but above the minimum length are considered merchantable logs and are given a predicted weight. Materials falling below the minimum length, because of the lack of bole wood between the last log and the merchantable top, are left in the woods and are designated as "residue" in the program.

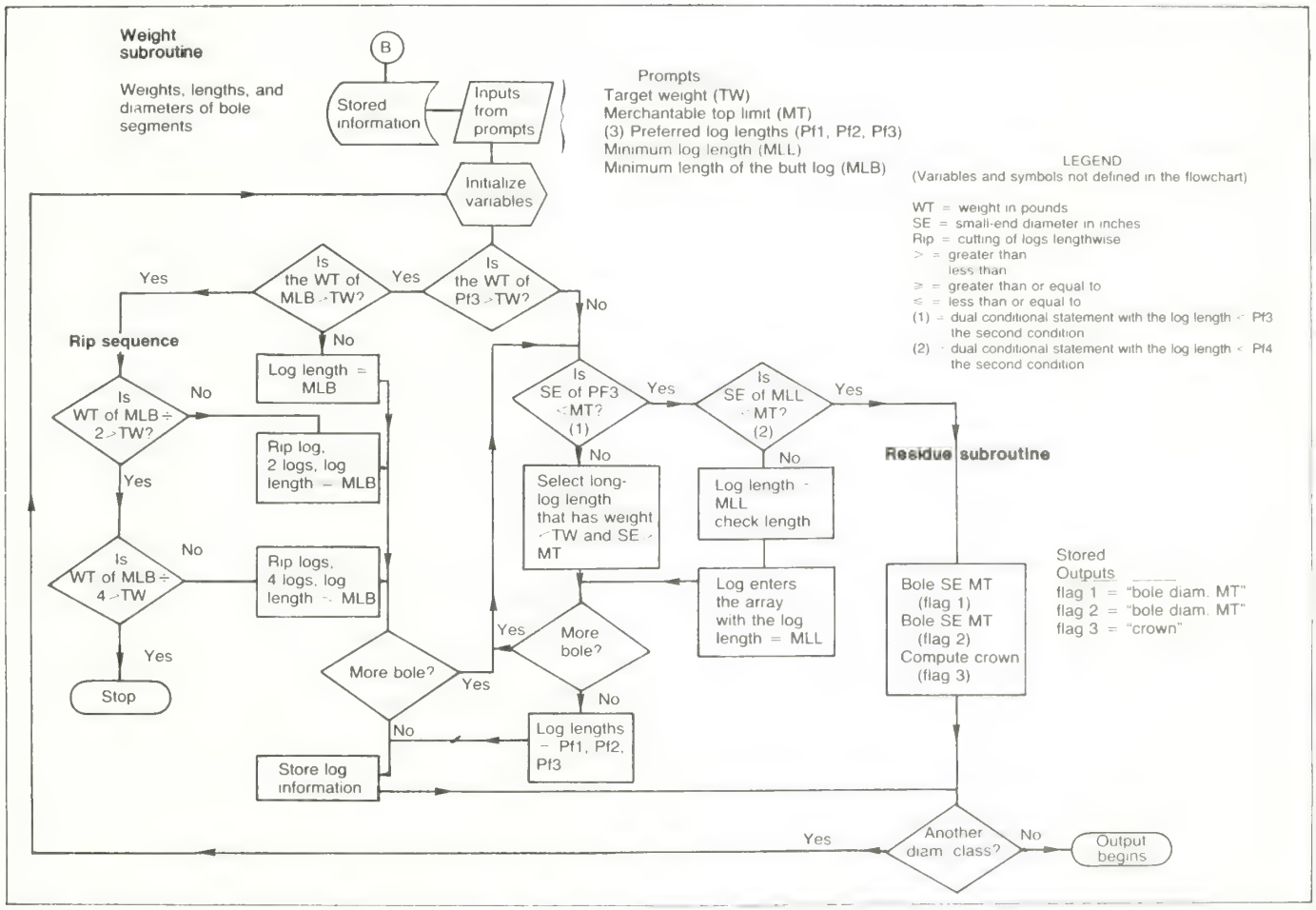

Weight subroutine
Weights, lengths, and diameters of bole segments
B
Stored information
Inputs from prompts
Prompts
Target weight (TW)
Merchantable top limit (MT)
(3) Preferred log lengths (Pf1, Pf2, Pf3)
Minimum log length (MLL)
Minimum length of the butt log (MLB)
LEGEND
(Variables and symbols not defined in the flowchart)
WT = weight in pounds
SE = small-end diameter in inches
Rip = cutting of logs lengthwise
> = greater than
< = less than
≥ = greater than or equal to
≤ = less than or equal to
(1) = dual conditional statement with the log length < Pf3 the second condition
(2) = dual conditional statement with the log length < Pf4 the second condition
Initialize variables
Is the WT of MLB > TW?
Yes
Is the WT of Pf3 > TW?
Yes
No
Rip sequence
No
Log length = MLB
Is WT of MLB ÷ 2 > TW?
No
Rip log, 2 logs, log length = MLB
Yes
Is WT of MLB ÷ 4 > TW
No
Rip logs, 4 logs, log length = MLB
Yes
Stop
More bole?
Yes
No
Store log information
Log lengths = Pf1, Pf2, Pf3
Is SE of PF3 < MT? (1)
Yes
No
Select long-log length that has weight < TW and SE > MT
Is SE of MLL > MT? (2)
Yes
No
Log length = MLL check length
Log enters the array with the log length = MLL
More bole?
Yes
No
Residue subroutine
Bole SE MT (flag 1)
Bole SE MT (flag 2)
Compute crown (flag 3)
Stored Outputs
flag 1 = "bole diam. MT"
flag 2 = "bole diam. MT"
flag 3 = "crown"
Another diam class?
Yes
No
Output begins

Figure 5—Flowchart of the subroutine that partitions the bole into logs.

The log weight table is produced next (fig. 6). Each tree or diameter class has a separate output that includes the number of merchantable logs, the total length of the bole used by the model, the estimated weight of the bole, and the lengths and estimated weights of the logs. The bole and log lengths printed in the table will be slightly different from the total height of the bole and preferred lengths of the logs that the user enters. This difference is the result of rounding error associated with the iterative process. The number of iterations that the user enters and the length of the bole contribute to the length that the model uses to iteratively sum the weights (segment length equals total height divided by the number of iterations). The greater the number of iterations or the shorter the bole, the closer the length in the table will be to the lengths entered by the user.

CRUISE INFORMATION FOR OLD-GROWTH DOUGLAS-FIR

DIAMETER CLASS (IN)	TOTAL HEIGHT(FT)
10	85
20	95
30	110
40	165
50	180

---------- BUCKING INFORMATION FOR OLD-GROWTH DOUGLAS-FIR----------

PREFERRED BUCKING LENGTHS (FT) ARE:

OPTIMUM LOG LENGTH = 41
SECOND LOG LENGTH = 35
THIRD LOG LENGTH = 25
MINIMUM LOG LENGTH = 8
MINIMUM BUTT LOG = 17

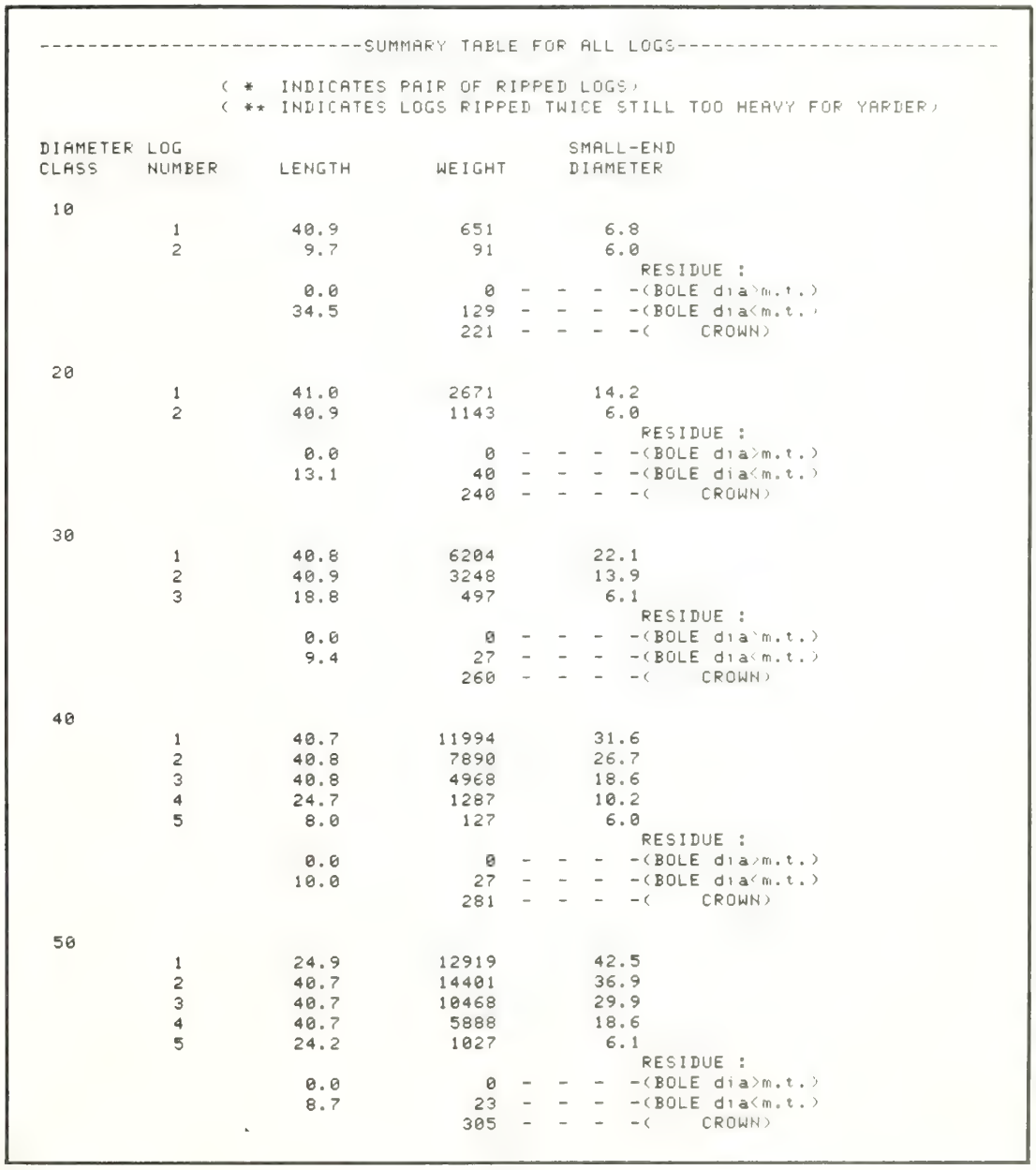
MERCHANTABLE TOP DIAMETER (IN) = 6

MAXIMUM ALLOWABLE LOG WEIGHT (LB) = 15000

LOG LENGTH/WEIGHT TABLE FOR OLD-GROWTH DOUGLAS-FIR

		LOG NUMBER					
	TOTAL	1	2	3	4	5	6
DIAMETER CLASS==> 10							
(2 LOGS)							
LENGTHS=	51	40.9	9.7	0.0	0.0	0.0	0.0
EST WEIGHTS =	742	651	91	0	0	0	0
DIAMETER CLASS==> 20							
(2 LOGS)							
LENGTHS=	82	41.0	40.9	0.0	0.0	0.0	0.0
EST WEIGHTS =	3815	2671	1143	0	0	0	0
DIAMETER CLASS==> 30							
(3 LOGS)							
LENGTHS=	101	40.8	40.9	18.8	0.0	0.0	0.0
EST WEIGHTS =	9948	6204	3248	497	0	0	0
DIAMETER CLASS==> 40							
(5 LOGS)							
LENGTHS=	155	40.7	40.8	40.8	24.7	8.0	0.0
EST WEIGHTS =	26265	11994	7890	4968	1287	127	0
DIAMETER CLASS==> 50							
(5 LOGS)							
LENGTHS=	171	24.9	40.7	40.7	40.7	24.2	0.0
EST WEIGHTS =	44704	12919	14401	10468	5888	1027	0

Figure 6—Computer summary of the log weight table.



```
----------------------------SUMMARY TABLE FOR ALL LOGS----------------------------

              ( *  INDICATES PAIR OF RIPPED LOGS)
              ( ** INDICATES LOGS RIPPED TWICE STILL TOO HEAVY FOR YARDER)

DIAMETER LOG                                        SMALL-END
CLASS    NUMBER      LENGTH        WEIGHT           DIAMETER

 10
            1          40.9           651             6.8
            2           9.7            91             6.0
                                                   RESIDUE :
                       0.0             0  -  -  -  -(BOLE dia>m.t.)
                      34.5           129  -  -  -  -(BOLE dia<m.t.)
                                     221  -  -  -  -(     CROWN)

 20
            1          41.0          2671            14.2
            2          40.9          1143             6.0
                                                   RESIDUE :
                       0.0             0  -  -  -  -(BOLE dia>m.t.)
                      13.1            40  -  -  -  -(BOLE dia<m.t.)
                                     240  -  -  -  -(     CROWN)

 30
            1          40.8          6204            22.1
            2          40.9          3248            13.9
            3          18.8           497             6.1
                                                   RESIDUE :
                       0.0             0  -  -  -  -(BOLE dia>m.t.)
                       9.4            27  -  -  -  -(BOLE dia<m.t.)
                                     260  -  -  -  -(     CROWN)

 40
            1          40.7         11994            31.6
            2          40.8          7890            26.7
            3          40.8          4968            18.6
            4          24.7          1287            10.2
            5           8.0           127             6.0
                                                   RESIDUE :
                       0.0             0  -  -  -  -(BOLE dia>m.t.)
                      10.0            27  -  -  -  -(BOLE dia<m.t.)
                                     281  -  -  -  -(     CROWN)

 50
            1          24.9         12919            42.5
            2          40.7         14401            36.9
            3          40.7         10468            29.9
            4          40.7          5888            18.6
            5          24.2          1027             6.1
                                                   RESIDUE :
                       0.0             0  -  -  -  -(BOLE dia>m.t.)
                       8.7            23  -  -  -  -(BOLE dia<m.t.)
                                     305  -  -  -  -(     CROWN)
```

Figure 7—Computer summary with details of log lengths, weight, small-end diameters, and residue information.

Subroutine that calculates residue—The residue subroutine computes three weights: (1) the material that falls below the minimum merchantable length and has a diameter larger than the merchantable top (m.t.), (2) the material with a diameter smaller than the merchantable top; and (3) the continuous crown, which includes the branches and needles. The information is printed in the table as (bole dia. > m.t.) (bole dia. < m.t.), and (crown) (fig. 7). The crown model was developed by Snell and Max (1985) for old-growth Douglas-fir.

Model Validation

Data collected from the 18 sample trees were used to develop the coefficients for the prediction equations used in the program. The measurements taken from the 93 validation trees (DBHob, totht, and the lengths of the 326 logs) were entered into the program , and weights of the boles and logs were estimated. Estimated weights were compared with actual weights to determine a measure of bias and accuracy. Bias was calculated as the mean of the differences between the actual and the estimated weights for logs and boles. The accuracy was calculated as the mean of the absolute differences between the actual and the estimated weights.

Results and Discussion

Model Development

Parameter estimates from the regression analysis are provided in table 3. The conversion and taper equations (fig. 2) have high levels of significance (R^2) and low standard error of the estimates (SE). The green density equation, however, produced a rather low R^2 and a high SE (fig. 3). The green density equation is similar to those reported for old-growth Douglas-fir in southern Washington by Pong and others (1986). The variation in measured values around the function indicates that even within homogeneous old-growth stands moisture levels are highly variable among trees. The curvilinear form of the equation is characteristic, however, of most old-growth conifers and expresses high densities in the lowest portion of the bole, drop offs in density in the lower to middle portion, and gradual increases in density in the upper bole. The top portion of the bole was highly variable because of the greater proportion of sapwood (active transpiration) and the variable conditions of the crown (size and vigor) among the trees sampled.

Model Validation

Tables 4 and 5 provide the summary statistics comparing the estimated weights with the actual weights for the 93 validation trees (326 logs).

Table 4 summarizes the validation for logs located in various positions within the boles. Different bole positions demonstrated slightly varying accuracy levels with the butt logs having the lowest relative error (0.5 percent bias and 5.9 percent average error of the estimate) and the top logs the highest (2.8 percent bias and 10.5 percent average error of the estimate). If this model had been used for making decisions concerning load assembly in this stand (for aerial logging), loads containing numerous upper logs would have been susceptible to more overloads and underruns during aerial yarding because of greater error in estimates of log weights. Theoretically, loads containing the entire bole or loads with a variety of butt, middle, and top logs would tend to be more accurate in weight because of the canceling of positive and negative bias from the lower to upper portions of the bole. This is reflected in table 4 by the pooled bias of 0.1 percent.

Table 5 divides the validation trees into five diameter classes. The largest and smallest of the tree sizes were the least accurate. Small trees (less than 21 inches) were slightly underestimated (0.5 percent bias) but had a high average error of the estimate (12.9 percent) as compared to other classes. As the diameter class increases, the trend reverses with an increase in the overestimation (plus bias).

Table 3—Summary statistics for prediction equations

Dependent variable	Regression constants						Statistical measures 1/		
	a	b1	b2	b3	b4	b5	n	R^2	SE
DBHib	-0.19	.87					18	0.99	0.73
Rob	1.00	-1.88	7.00	-15.36	15.32	-6.09	18	.95	4.09
Rib	1.00	-1.45	5.44	-12.99	13.76	-5.75	18	.94	4.85
ds(ob)	2.12	1.04					18	.99	1.34
ds(ib)	1.17	1.06					18	.93	1.81
gden	47.71	-39.09	73.45	-39.65			18	.18	3.11

1/ DBHib=-a+b1(DBHob);

Rob,Rib=a-b1(relht)+b2(relht)^2-b3(relht)^3+b4(relht)^4-b5(relht)^5;

ds(ob),ds(ib)=a+b1(DBHob);

gden=a-b1(relht)+b2(relht)^2-b3(relht)^3; where:

DBHib = diameter at breast height inside bark;

DBHOb = diameter at breast height outside bark;

Rob = diameter ratio outside bark;

Rib = diameter ratio inside bark;

ds(ob) = diameter outside bark at the base of the bole;

ds(ib) = diameter inside bark at the base of the bole;

gden = the green density of the wood;

n = sample size;

R^2 = coefficient of determination; and

SE = standard error of the estimate.

Table 4—Actual log weights as recorded on scales compared to estimated log weights with data grouped by bole position

Bole position	Sample size	Mean actual weight 1/	Mean estimated weight 2/	Bias 3/		Mean absolute difference 4/		Root mean squared difference 5/	
		--------Pounds----------			Percent	Pounds	Percent	Pounds	Percent
Pooled 6/	326	2800	2836	+36.0	1.3	211.6	7.6	297.0	10.6
Butt	86	4499	4475	-24.4	.5	266.1	5.9	345.8	7.7
Second log	86	3378	3472	+93.9	2.8	271.3	8.0	367.5	10.9
Middle	84	1901	1945	+43.5	2.3	178.8	9.4	233.8	12.3
Top	68	1012	1040	+28.4	2.8	105.9	10.5	171.3	16.9

1/ Measured on truck scales.

2/ Estimated with the computer model.

3/ Bias is the mean of the differences between the actual and the estimated weights. The value is converted to a percentage by dividing the bias by the mean actual weight multiplied by 100.

4/ Accuracy measure: the mean of the absolute differences between the actual and the estimated weights. The value is converted to a percentage by dividing the mean absolute difference by the mean actual weight.

5/ Accuracy measure that will emphasize the error associated with large weights: the square root of the mean of the squared differences between the actual and estimated weights. The value is converted to a percentage by dividing the root mean squared difference by the mean actual weight.

6/ "Pooled" contains all logs within the bole; butt is the first log in the bole.

Table 5—Actual log weights as recorded on scales compared to estimated log weights with data grouped by diameter class

Tree diameter	Sample size	Mean actual weight 1/	Mean estimated weight 2/	Bias 3/		Mean absolute difference 4/		Root mean squared difference 5	
		Pounds			Percent	Pounds	Percent	Pounds	Percent
Pooled 6/	326	2800	2836	+36.0	0.1	211.6	7.6	297.0	10.6
20.9	12	1485	1478	-7.4	.5	191.4	12.9	279.5	18.8
21-24.9	75	2228	2151	-77.7	3.5	168.4	7.6	218.0	9.8
25-28.9	108	2666	2650	-15.2	.6	208.7	7.8	300.8	11.3
29-32.9	106	3108	3209	+101.1	3.3	204.1	6.6	279.0	8.9
33	25	4414	4814	+344.0	7.8	395.2	9.0	498.0	11.3

1/ Measured on truck scales.

2/ Estimated with the computer model.

3/ Bias is the mean of the differences between the actual and the estimated weights. The value is converted to a percentage by dividing the bias by the mean actual weight multiplied by 100.

4/ Accuracy measure: the mean of the absolute differences between the actual and the estimated weights. The value is converted to a percentage by dividing the mean absolute difference by the mean actual weight.

5/ Accuracy measure that will emphasize the error associated with large weights: the square root of the mean of the squared differences between the actual and estimated weights. The value is converted to a percentage by dividing the root mean squared difference by the mean actual weight.

6/ "Pooled" contains all tree sizes. The other categories are diameter outside bark, 4-1/2 feet from the base of the tree.

Application

The Iterative Weight Program (ITWGHT) [5/]

The iterative weight program (ITWGHT) program is available from the authors as an example of how we applied the iterative technique to help solve log production problems encountered in aerial logging operations. The program was designed for a specific application (log and residue weight tables), and the user may want to modify the language (for use on other computers) and structure of the program to meet other applications.

The iterative approach to estimating bole and log weights can aid the user in determining the potential merchantable and unmerchantable products available from the standing timber so that yarding operations can be evaluated before harvesting. The program is interactive, so the user has a multitude of options for data entries; for example, the program will accept standard inventory and harvesting information, such as DBH distributions, average height of the timber, various bucking lengths for log production, any merchantable top limit, and a target weight for the yarder.

ITWGHT is structured so that all iterative calculations are stored in arrays that can be passed to other programs. (Note: the user can save memory by eliminating the storage of arrays.) The program "Filer" is also available to aid the user in building files from inventory data and inserting new prediction equations into ITWGHT.

Developing Additional Prediction Equations and Operating ITWGHT

Collecting data for the program—An inventory (cruise) of the harvest unit is needed to develop stand characteristics, such as DBH distributions for each species, average tree heights for each diameter class, and the number of stems within each class. The user may wish to follow the inventory with a sampling of trees to build equations that are site specific for predicting diameters (taper equations) and green density rather than use the equations presented here. The sampling may require stratification of species, diameter classes, and locations within the harvest unit, if there is high variability within the stand. The variablity of the stand can be evaluated by the inventory data. A wide representation of diameter classes and the presence of more than two species will require the selection of a larger number of sample trees because of the need to build separate equations for each species and the requirement of sampling across the entire diameter range. Another indication of variation is the physical characteristics of the site. The presence of numerous exposures (aspects), the steepness and length of the slope, the appearance of depressions and dissections within the slope, and rock outcroppings are a few examples of physical site factors that can create strata within the stand where taper and green density will vary among trees of the same species.

The way in which the sampling rules are determined will be directly linked to the objectives of the user (the intended application of the model). For example, the user in cable logging systems may need to know what the heaviest logs in the unit will weigh or the maximum log length that can be bucked from the larger trees and still be yarded to the landing. The yarding system is often limited by the cable size and by the capacity of the yarder. In such cases, the sampling is directed toward the larger trees in the unit to maximize the accuracy within that size class. The actual precision and accuracy achieved by the model will also depend on the variability in the strata.

[5/]The iterative weight program (ITWGHT) was programmed in Hewlett-Packard's basic control language on a Hewlett-Packard 9845B microcomputer. The authors are currently working on an IBM PC version in BASIC and FORTRAN

For applications covering the entire stand, such as in aerial logging, every tree has to be considered, and the sampling must draw from each species and diameter class. The user will need to balance the higher costs associated with a greater number of sample trees with the anticipated savings in logging efficiency (greater payloads with less aborts) because of more accurate estimates of load weight.

The site-specific diameter and green density data are then subjected to regression analysis, and new coefficients are inserted into the computer program. This step requires access to a statistical software package that includes polynomial regression.

How To Use the Results

The ITWGHT model allows preharvest evaluations of changes in various product mixes for a given timber resource (before the harvest) by changing the preferred log lengths and the target weight. For example, a target weight of 15,000 pounds may restrict the bucking of butt logs that are over 35 feet for trees with a DBH exceeding 50 inches, as shown in the log length/weight table (fig. 6). More aborts can be risked with a higher target weight because of the monetary value of the butt log in these large trees. Another option is to cut a short butt log or even an unmerchantable end and buck a longer second log. The yarding of whole boles for the smaller trees (up to 30 inches) can minimize log waste encountered in bucking operations taking place in the woods. Each bucking option can be analyzed before bucking instructions are presented to the crew. A crew's falling and bucking costs can be easily inserted into the model. The model allows the user to analyze actual stand data and to solve critical log production problems prior to any harvesting.

Conclusion

A computer model was developed that iteratively calculates the weight of the entire bole to any merchantable top and the weight of logs within the bole for old-growth Douglas-fir. The model provides accurate estimates of weight for logs as compared to the actual weights measured on scales. This approach to weight modeling appears to be an important tool for planning and evaluating logging operations. The potential for higher valued products can be increased during preharvest analysis with the model by allowing managers to provide accurate and detailed instructions to bucking crews. The flexible approach to estimating weight of logs and other tree components can result in cost savings by providing better estimates of payloads. Better estimates of payloads can lead to greater harvesting efficiency and increased safety.

Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.540	Centimeters
Feet	0.305	Meters
Cubic feet	0.028	Cubic meters
Pounds	0.454	Kilograms
Acres	0.405	Hectares
Pounds per cubic feet	16.019	Kilograms per cubic meter

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A computer model that estimates the green weights of standing trees was developed and validated for old-growth Douglas-fir. The model calculates the green weight for the entire bole, for the bole to any merchantable top, and for any log length within the bole. The model was validated by estimating the bias and accuracy of an independent subsample selected from the original stand. Calculated weights were compared to actual weights as measured on truck scales. The model accurately estimated the weight of logs (less than 10 percent error) and provides an estimation technique that is expected to have application for various elements of timber management.

Keywords: Models, weight scaling (log), log weights, computer programs/programing.

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Effects of Fertilization on Growth and Foliar Nutrients of Red Alder Seedlings

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Abstract

Radwan, M.A. 1987. Effects of fertilization on growth and foliar nutrients of red alder seedlings. Res. Pap. PNW-RP-375. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 14 p.

Effects of P, K, Ca, Mg, S, Co, and Mo fertilizers on growth and foliar nutrients of red alder seedlings potted in Grove, Bunker, and Wishkah forest soils were determined. Growth in Grove soil was stimulated most by P, Ca, and P + Ca + Mg + K + S. Growth in Bunker soil was improved only by P. In Wishkah soil, best growth was obtained when P was used alone; all fertilizer mixtures produced less growth. Results indicated the potential of fertilizer to increase alder production and suggested caution in using fertilizer mixtures because they may materially reduce growth response.

Keywords: Fertilizer effects, growth response, nutrients, red alder, seedling growth.

Summary

Two experiments were conducted to determine effects of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), cobalt (Co), and molybdenum (Mo) fertilizers on growth and foliar nutrients of red alder (*Alnus rubra* Bong.) seedlings grown in three different forest soils in a lathhouse. Soil series used were Grove and Bunker in experiment 1 (1982) and Grove and Wishkah in experiment 2 (1983). Test soils are among those soils found under natural stands of alder in western Washington. In experiment 1, fertilizers were: (1) triple superphosphate (P); (2) KCl (K); (3) $CaCo_3$ (Ca); (4) $MgCl_2$ (Mg); and (5) Na_2SO_4 (S). In experiment 2, fertilizers were: (1) P; (2) P + Ca; (3) P + Ca + Mg; (4) P + Ca + Mg + K;(5) P + Ca + Mg + K + S; (6) P + Ca + Mg + K + S + $CoCl_2$(Co); and (7) P + Ca + Mg + K + S + Co + MoO_3 (Mo). In both experiments, fertilization was done in May. In experiment 1, fertilizers were mixed with the top 2 cm of mineral soil. In experiment 2, mineral soil was covered with a layer of forest floor, and fertilizers were spread over the forest floor without mixing. Growth in the unamended soils was much better in Grove, with or without forest floor, than in the Bunker or Wishkah soils; the latter soils were especially low in extractable P. Fertilization significantly affected growth in all test soils. Growth in the Grove soil was enhanced most by the P, Ca, and P + Ca + Mg + K + S fertilizers. Growth in Bunker soil was increased only by the P treatment; all other fertilizers were ineffective. Growth in Wishkah soil was improved most by the P fertilizer alone; all fertilizer mixtures produced significantly less growth than that obtained with P alone. Foliar nutrient concentrations of the unfertilized trees were generally within the range of values reported in the literature for red alder. Fertilization influenced nutrient concentrations, and trends varied by soil and fertilizer treatment. Amounts of nutrients in the leaves were significantly increased by the effective fertilization treatments, reflecting enhancement of dry matter production and nutrient uptake and use. Nutrient additions resulting from fertilization differed by soil, with the macronutrients showing the largest gains. Results indicated the potential of fertilizer, especially P fertilizer, to increase growth. Results also suggested caution in using fertilizer mixtures because they may materially reduce growth response.

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Introduction

Red alder (*Alnus rubra* Bong.) is the major hardwood species in the Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) region of the Pacific Northwest. Red alder is known for its rapid juvenile growth, for its ability to fix atmospheric nitrogen (N), and for adding nutrient-rich leaflitter to the soil (Gessel and Turner 1974, Radwan and others 1984, Tarrant and Trappe 1971). The inherent characteristics of alder make it an excellent choice for short-rotation, biomass-for-energy plantations. Alder is also gaining importance because of the steady increase in the commercial value of its wood. In addition, the species has been recommended for planting on surface-mine spoils and has been suggested as a biological source of nitrogen for use in admixtures or crop rotations with conifers (DeBell 1979).

Presently, little literature exists on the nutrition of alder species, including red alder. European black alder (*Alnus glutinosa* [L.] Gaertn.) is reported to require molybdenum (Mo) (Becking 1961) and cobalt (Co) (Bond and Hewitt 1962) for symbiotic N_2-fixation. Pregent and Camire (1985) estimate critical levels of selected nutrients in foliage of green (*Alnus crispa* [Ait.] Pursh) and black alder. Lime and phosphorus (P) enhanced growth of black alder (Seiler and McCormick 1982). Applications of Co (Russell and others 1968) and P and calcium (Ca) fertilizers (Hughes and others 1968) improved growth of red alder. Still, much more nutritional information about alder is needed if maximum growth and N_2-fixation are to be obtained.

This study was designed to assess effects of various fertilizers applied, singly and in combination, to red alder seedlings grown in different soils.

Materials and Methods

The study consisted of two separate experiments, with seedlings from the same seed source used in both experiments. Experiment 1 (1981-82) compared untreated controls and five different fertilizers applied singly at two different rates each. In experiment 2 (1982-83), comparisons were made between controls, a single fertilizer, and six different fertilizer mixtures.

Test Soils

The soil series used in the study were Grove and Bunker for experiment 1 and Grove and Wishkah for experiment 2. These soils differ greatly in many of their properties, and they are among the soils found under natural stands of red alder in western Washington. For each soil series, the forest floor and the underlying mineral soil to a depth of 20 cm were collected separately. Large pieces of stems, roots, and rocks were removed and samples were mixed thoroughly. Soils were placed in 7.6-L plastic pots. Each pot, with a top of about 3×10^{-6} ha, contained about 6 kg of mineral soil, on an air-dry basis. In experiment 2, mineral soil in each pot was covered with about 100 g of forest floor spread evenly over the top to simulate natural conditions.

Representative subsamples of the mineral soils were passed through a 2-mm sieve, and sieved subsamples were used for determining selected chemical characteristics as shown below. Soil subsamples used to determine N and all samples of forest floor materials were ground to a fine powder before analysis.

Test Seedlings

Seeds for both experiments were collected from a single tree growing at Capitol Forest, west of Olympia. In July (1981 for experiment 1 and 1982 for experiment 2) seeds were sown in styroblock containers filled with 1:1 (v/v) mixture of peat moss and vermiculite. Seeds in the cavities were covered with a thin layer of silica grit to discourage algal growth, and the containers were kept in a roofed lathhouse. Water was added as required during the first 2 weeks after sowing. Seedlings were then watered with a dilute

(1:1, v/v) nutrient solution (Hoagland and Arnon 1950) once a week, and cavities were flushed with water once a month to prevent accumulation of excess salts. Five weeks after sowing, seedlings were thinned to one per styroblock cavity, and seedlings were inoculated with red alder endophytes from a single preparation of crushed-nodule inoculum. In mid-September, addition of nutrient solution was discontinued to slow growth and encourage budset and cold hardiness.

In early spring 1982 and 1983 (for experiments 1 and 2, respectively), the cavities were flushed with water several times to remove as much of the nutrients remaining in the potting mixture as possible. Seedlings were individually planted in the plastic pots containing the different soils. A three-seedling group served as the basic experimental unit. Three groups of three seedlings each (three replications and nine seedlings) were used for each soil-fertilizer treatment in each experiment. Seedlings were placed, as groups of three, at random on low wooden benches in the roofed lathhouse.

Treatments

Experiment 1 consisted of 10 fertilization treatments and an untreated control (C). Triple superphosphate, potassium chloride, calcium carbonate, magnesium chloride, and sodium sulfate were used as sources of P, potassium (K), Ca, magnesium (Mg), and sulfur (S), respectively.The fertilizers were applied singly on an area basis at low and high rates equivalent to 150 and 300 kg P/ha; 100 and 200 kg K/ha; 1200 and 2400 kg Ca/ha; 75 and 150 kg Mg/ha; and 75 and 150 kg S/ha. The nutrients were applied to the seedlings in May 1982 by mixing the fertilizer with the top 2 cm of soil and watering the pots the same day.

Experiment 2 had seven fertilization treatments and an untreated control. Triple superphosphate, calcium carbonate, magnesium chloride, potassium chloride, sodium sulfate, cobalt chloride, and molybdenum trioxide supplied the nutrients P, Ca, Mg, K, S, Co, and Mo. The fertilizers were applied in that order and in an additive manner to yield the seven fertilization treatments: P; P + Ca; P + Ca + Mg; P + Ca + Mg + K; P + Ca + Mg + K + S; P + Ca + Mg + K + S + Co; and P + Ca + Mg + K + S + Co + Mo. Rates of application per hectare, on an area basis, were equivalent to 300 kg P; 1800 kg Ca; 75 kg Mg; 100 kg K; 75 kg S; 0.1 kg Co; and 0.5 kg Mo. Fertilizers were placed around the potted seedlings on top of the forest floor, without mixing, to simulate field fertilization. Seedlings were watered the same day fertilizers were applied.

Growth Measurements

Height and diameter of the test seedlings were determined before treatment in May and in September when the seedlings were harvested at the end of each experiment. At harvest, shoots and roots were separated by clipping at the root collar. The eight healthiest, fully expanded leaves were cut from each plant to determine the average weight of mature leaves; the same material was used for foliar chemical analysis. Roots were washed free of soil, and excess moisture was removed with blotting towels. Shoots, roots, and leaves were cut up and dried to constant weight at 65 °C. Height, diameter growth, and dry weight of shoots, roots, and leaves were calculated.

Processing and Chemical Analysis of Foliage

Ovendry leaves, separated by replication, soil, and treatment, were ground to 40 mesh in a mill and stored in plastic containers until analyzed.

Total N and total S were determined, respectively, by the micro-Kjeldahl procedure (Bremner and Mulvaney 1982) and by the turbidimetric method of Butters and Chenery (1959). Other nutrients were determined as follows: P by the molybdenum blue method (Chapman and Pratt 1961), and K, Ca, Mg, copper (Cu), iron (Fe), zinc (Zn), and manganese (Mn) by atomic absorption (Perkin-Elmer Corporation 1976).

Chemical Analysis of Soils and Forest-Floor Materials

Mineral soils and forest-floor materials were characterized by determining pH on 1:1 mixtures with water by glass electrode, total N by the Kjeldahl method (Bremner and Mulvaney 1982), total S by turbidimetric method (Butters and Chenery 1959), and Bray-2-extractable P according to Bray and Kurtz (1945). Mineral soils were also analyzed for cation exchange capacity by NH_4OAc extraction (Chapman and Pratt 1961) and for exchangeable K, Ca, and Mg (NH_4OAc extraction) by atomic absorption (Perkin-Elmer Corporation 1976).

Statistical Analysis

For each experiment, growth and foliar-nutrient data were treated by analysis of variance to assess effects of soils and fertilization treatments; means within soils were separated by Tukey's test as required (Snedecor 1961). Differences were considered significant at $P < 0.05$.

Results and Discussion

The Study Soils

Soil samples used in the study differed in many of their characteristics (table 1). Parent material of the mineral soil was glacial for Grove and Wishkah and basalt for Bunker. Mineral soils of Bunker and Wishkah were particularly higher in N, S, and cation exchange capacity and lower in extractable P than was Grove soil. Mineral soil of Wishkah was lowest in pH and exchangeable K and Ca, and Bunker soil was highest in exchangeable Mg. Forest-floor materials varied in pH, N, S, and P in the same order as did the mineral soils. Nitrogen and S were higher and P was lower in forest floors of Bunker and Wishkah than in those of Grove. The forest floor of Wishkah had the lowest pH and that of Bunker had the lowest P.

Table 1—Selected characteristics of study soils

Item	Grove soil		Bunker soil		Wishkah soil	
	Mineral soil	Forest floor	Mineral soil	Forest floor	Mineral soil	Forest floor
Soil parent material	Glacial	—	Basalt	—	Glacial	—
pH	5.55	5.02	5.20	4.50	4.48	3.80
Kjeldahl N (percent)	.20	.54	.30	.82	.30	.72
Total S (percent)	.02	.07	.05	.10	.05	.10
Bray 2-extractable P (p/m)	65.0	130.0	5.2	24.0	3.5	45.0
Cation exchange capacity (meq/100 g)	23.7	—	37.2	—	34.6	—
Exchangeable (NH_4OAc) K (meq/100 g)	.4	—	.5	—	.2	—
Exchangeable (NH_4OAc) Ca (meq/100 g)	2.0	—	2.2	—	.6	—
Exchangeable (NH_4OAc) Mg (meq/100 g)	.3	—	.6	—	.3	—

Seedling Growth

In both experiments, seedling growth was very slow in the cool spring. Growth accelerated with the higher temperatures during the summer and was essentially complete at harvest in September. Harvested seedlings were free of disease and insect damage. Roots were variously nodulated with great differences in nodule size. Nodule weights were not determined, though, because collecting the nodules quantitatively and without root fragments was impossible.

In both experiments, significant soil, fertilizer, and soil x fertilizer interactions were found in all the growth variables examined.

Experiment 1—Without fertilizer, seedling growth was much better in Grove than in Bunker soil (table 2). This was shown, to varying degrees, by the different variables measured; for example, seedling dry weight and height growth were, respectively, 17.4 and 7.6 times greater in Grove than in Bunker soil. The two soils differed greatly in their content of available nutrients (table 1).

Fertilization significantly affected growth in both soils, and effects varied by fertilizer and rate of application. In the Grove soil, several fertilization treatments were effective. Growth was enhanced most, however, by the P and Ca fertilizers, although concentrations of the native, extractable P and exchangeable Ca in the soil seemed adequate (table 1). The favorable effects of the P and Ca fertilizers agreed with earlier findings for seedlings of red alder (Hughes and others 1968) and European black alder (Seiler and McCormick 1982).

Averaged over both the low and high treatments, fertilization increased height growth and seedling dry weight over the controls by 64 and 94 percent for P and by 61 and 71 percent for Ca (table 2, fig. 1). S was the least effective fertilizer in Grove soil, although total S in the soil seemed low (table 1).

Growth in the Bunker soil was significantly improved only by the P fertilizer, which produced dramatic results; average responses to this fertilizer of increased height growth and seedling dry weight over the controls were 895 and 1780 percent, respectively (table 2, fig. 1). The Bunker soil was especially low in native, extractable P (table 1), and this element was clearly the primary nutrient limiting growth in that soil. Without P additions, seedlings were visibly stunted, and many leaves had brown spots. The purplish color of leaves typical of P deficiency in other plant species (Sprague 1964) was not observed, however.

Table 2—Effect of fertilization on growth of red alder seedlings in 2 forest soils (experiment 1)[1]

Treatment	Diameter growth	Height growth	Leaf dry weight	Root dry weight	Shoot dry weigh
	Millimeters	*Centimeters*		*Grams*	
			GROVE SOIL		
C	6.2d	32.5c	0.28e	3.1c	5.6d
P, low	6.7bcd	49.4ab	.42b	4.0bc	9.0bc
P, high	8.1a	57.3a	.54a	6.2a	14.6a
K, low	6.3d	45.1b	.31de	3.5bc	7.0cd
K, high	6.8bcd	51.9ab	.33cde	4.4abc	8.7bc
Ca, low	7.1a-d	46.9ab	.42b	4.7abc	8.7bc
Ca, high	7.6ab	57.5a	.49ab	5.2ab	11.2b
Mg, low	7.4abc	49.9ab	.41bc	4.8abc	9.5bc
Mg, high	6.6cd	48.0ab	.39bcd	3.6bc	8.4c
S, low	6.9bcd	44.2bc	.34b-e	3.6bc	7.4cd
S, high	6.9bcd	43.3bc	.37bcd	3.8bc	7.6cd
			BUNKER SOIL		
C	1.2c	4.3b	0.04b	0.2b	0.3b
P, low	6.2a	41.7a	.33a	3.1a	6.3a
P, high	6.4b	43.8a	.35a	2.6a	6.7a
K, low	1.0c	3.0b	.03b	.2b	.3b
K, high	.9c	3.1b	.03b	.2b	.2b
Ca, low	.8c	3.4b	.04b	.2b	.3b
Ca, high	1.0c	3.5b	.03b	.2b	.3b
Mg, low	1.0c	3.9b	.03b	.2b	.3b
Mg, high	1.0c	3.8b	.03b	.2b	.3b
S, low	1.1c	3.6b	.03b	.2b	.3b
S, high	1.0c	3.2b	.03b	.2b	.2b

[1] C = untreated control. "Low" and "high" refer to application rates as follows: 150 and 300 kg P/ha, 100 and 200 kg K/ha, 1200 and 2400 kg Ca/ha, 75 and 150 kg Mg/ha, and 75 and 150 kg S/ha. Values are averages of 3 replications each. Within each soil, averages in the same column followed by different letters are significantly different at $p < 0.05$.

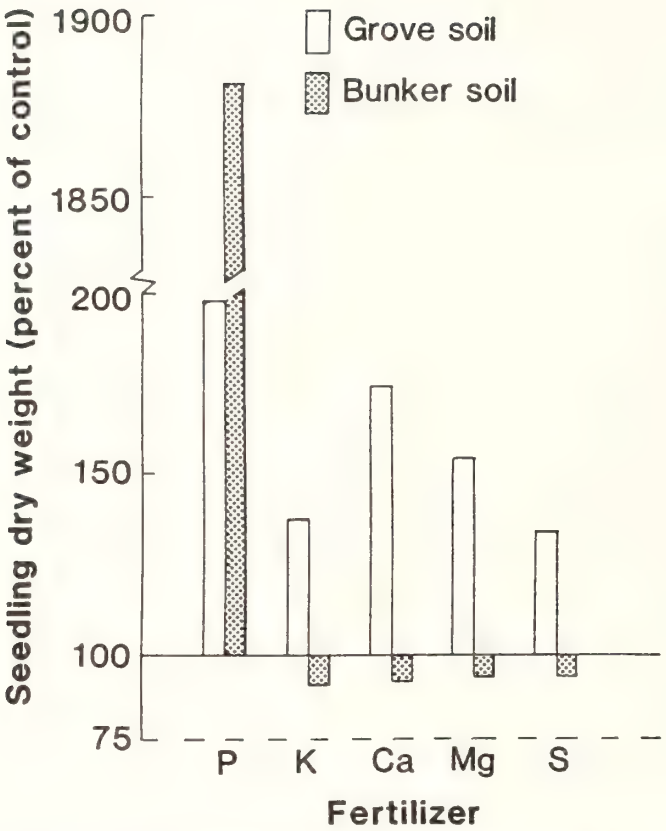

Figure 1—Effect of different fertilizers on seedling dry weight of red alder. Fertilizers were applied singly. Fertilizer sources and application rates are given in the text. Values are averages of two application rates.

Experiment 2— As in experiment 1, alder seedlings grew well in the unfertilized Grove soil (table 3). Seedling performance in that soil was not noticeably different in this experiment from that observed in experiment 1; forest floor was used to cover the mineral soil only in experiment 2. Tree growth in the unamended Wishkah soil was poor. Growth in that soil, however, was better than that in Bunker soil used in experiment 1 (table 2). This result may be explained by the additional supply of P provided by the Wishkah forest floor used to cover the mineral soil; no forest floor was used in the first experiment.

As with experiment 1, fertilization affected seedling performance in the two soils. Clearly, the forest floor placed on top of the mineral soil did not impede movement of the fertilizers, including P, to the roots. In both soils, all fertilizers increased growth, although not all increases were significant. Increases in dry weight of the Grove seedlings over the controls were lowest (21 percent) with the P + Ca + Mg + K fertilizer mixture and highest (66 percent) when S was added to that treatment (fig. 2). The reason for this difference is not readily apparent, although nutrient interactions may have been involved. In the Wishkah soil, growth was stimulated most by the P fertilizer alone, followed by the P + Ca mixture; increases in dry weight of seedlings over the controls by these treatments were 312 and 100 percent, respectively (fig. 2). All fertilizer mixtures produced significantly less growth than did P alone (table 3, fig. 2). Response to P was expected because the soil was low in native, extractable P (table 1). As with

Table 3—Effect of fertilization on growth of red alder seedlings in 2 forest soils (experiment 2)[1]

Treatment	Diameter growth	Height growth	Leaf dry weight	Root dry weight	Shoot dry weight
	Millimeters	*Centimeters*		*Grams*	
			GROVE SOIL		
1	4.6b	38.7b	0.28c	4.2c	6.8c
2	5.6a	51.0ab	.40ab	5.9a	11.0abc
3	5.7a	52.8ab	.36bc	5.4a	10.4abc
4	5.8a	53.0ab	.41ab	4.9abc	11.2abc
5	5.7a	45.1ab	.37ab	4.3c	9.1bc
6	6.5a	60.5a	.45a	5.3ab	13.0a
7	6.2a	55.0a	.42ab	5.0abc	11.8ab
8	6.2a	51.3ab	.41ab	5.1abc	11.1abc
			WISHKAH SOIL		
1	2.8c	15.2c	0.16c	1.3c	2.8c
2	5.5a	52.3a	.37a	5.5a	11.4a
3	4.2b	30.7bc	.25b	2.6b	5.6b
4	3.7bc	31.6b	.24bc	2.0bc	5.2b
5	3.7bc	28.1bc	.24bc	2.0bc	4.8bc
6	4.1b	28.7bc	.26b	2.3bc	4.8bc
7	3.9b	29.5bc	.28b	2.3bc	5.3bc
8	4.0b	30.3bc	.28b	2.2bc	5.3b

[1]Treatments: 1 = untreated control, 2 = 300 kg P/ha, 3 = 2 + 1800 kg Ca/ha, 4 = 3 + 75 kg Mg/ha, 5 = 4 + 100 kg K/ha, 6 = 5 + 75 kg S/ha, 7 = 6 + 0.1 kg Co/ha, 8 = 7 + 0.5 kg Mo/ha. Values are averages of 3 replications each. Within each soil, averages followed by different letters are significantly different at $p < 0.05$.

Bunker soil of experiment 1, P appeared to be the primary nutrient limiting growth in the Wishkah soil. The decreased growth responses to fertilizer mixtures were probably caused by nutrient interactions. Such interactions have been reported with red alder (Hughes and others 1968) and other forest tree species (Radwan and Shumway 1985). Use of fertilizer mixtures on red alder, therefore, is not advisable without further information.

Neither Co nor Mo appeared to affect growth in the Grove or Wishkah soils. Apparently, both soils contained enough of these elements to fully satisfy the growth requirements of red alder. Other possible sources of Co and Mo included fertilizer impurities and remnants of the nutrient solution used in production of the test seedlings. Results of greenhouse experiments by Russell and others (1968) suggest that the requirement for Co is quite low.

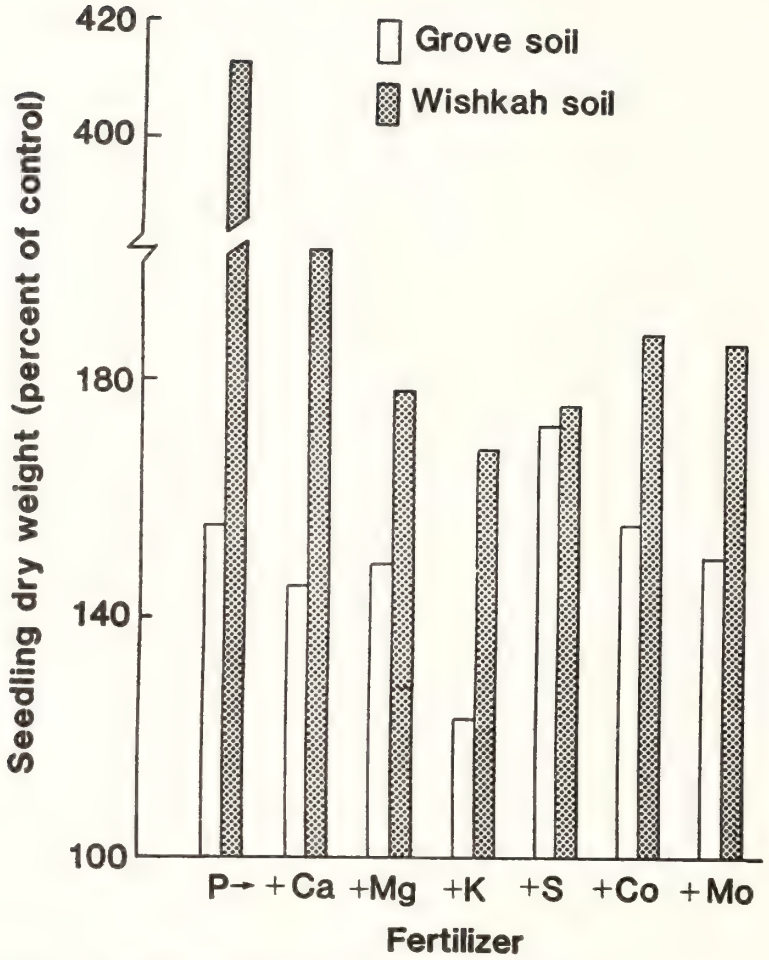

Figure 2—Effect of different fertilization treatments on seedling dry weight of red alder. Fertilizers were applied in the order shown in an additive manner; that is, P, P + Ca, P + Ca + Mg, and so on. Fertilizer sources and application rates are given in the text.

Foliar Nutrients

In both experiments, with few exceptions, concentration and content of the various foliar nutrients varied significantly by fertilizer. Also, in experiment 2, significant soil and soil x fertilizer interactions were found for concentration and content of several nutrients.

Experiment 1—Leaves from seedlings grown in Bunker soil were not analyzed. Leaves from all Bunker plants, except those from the P treatments, were very small and did not provide enough material for chemical analysis.

Nutrient concentrations in foliage of the unfertilized seedlings grown in Grove soil (table 4) were generally within the range of values reported in the literature for field-grown red alder (DeBell and Radwan 1984) and green alder (Grigal and others 1979, Henry 1973). Fertilization affected nutrient concentrations in foliage of the Grove seedlings, and trends varied by nutrient and rate of application. With only three exceptions (K-high, Mg-low, and Mg-high), fertilizers containing P, K, Ca, Mg, and S did not significantly increase the concentration of these nutrients in the foliage. This was probably caused by dilution resulting from increased growth (table 2). In contrast, some

Table 4—Effect of fertilization on foliar nutrients of red alder seedlings grown in Grove soil (Experiment 1)[1]

Treatment	Nutrient									
	N	P	S	Ca	K	Mg	Cu	Fe	Zn	Mn
	CONCENTRATION									
	Percent						*Parts per million*			
C	2.45ab	0.18bc	0.20a	0.97a	1.17a	0.23c	11ab	359a	89a	1367bc
P, low	2.44ab	.17c	.19ab	.88ab	1.07bcd	.23c	9ab	198bc	67ab	571def
P, high	2.69a	.17c	.18ab	.87ab	.86d	.23c	8b	133c	47b	294f
K, low	2.30b	.19ab	.18ab	.94ab	1.29ab	.24c	10ab	369a	92a	1726ab
K, high	2.19b	.18bc	.17b	.89ab	1.46a	.22c	10ab	306ab	92a	1880ab
Ca, low	2.41ab	.19ab	.18ab	.81abc	1.10bc	.19c	11ab	260abc	81a	660def
Ca, high	2.44ab	.18bc	.18ab	.85ab	1.01cd	.20c	11ab	173bc	72ab	406ef
Mg, low	2.21b	.18bc	.18ab	.90ab	1.09bcd	.36b	11ab	223abc	85a	1934ab
Mg, high	2.21b	.21a	.18ab	.84abc	1.10bc	.43a	12a	155bc	92a	2258a
S, low	2.41ab	.18bc	.20a	.76bc	1.24abc	.21c	11ab	275abc	74ab	1009cd
S, high	2.44ab	.18bc	.19ab	.66c	1.13bc	.20c	11ab	266abc	62ab	898cde
	CONTENT									
	Milligrams per leaf						*Micrograms per leaf*			
C	6.8d	0.5e	0.6c	2.7c	3.2b	0.6e	3b	98a	25ab	381cde
P, low	10.2bc	.7bcd	.8abc	3.7abc	4.5a	1.0cd	4ab	82a	28ab	234e
P, high	14.6a	.9a	1.0a	4.8a	4.6a	1.2bc	5a	72a	25ab	162e
K, low	7.2cd	.6cd	.6c	2.9bc	4.0ab	.7de	3b	116a	29ab	544cd
K, high	7.3cd	.6cd	.6c	2.9bc	4.8a	.7de	3b	101a	31ab	623bc
Ca, low	10.1bc	.8ab	.8abc	3.4bc	4.6a	.8de	4ab	109a	34ab	276e
Ca, high	12.0ab	.9a	.9ab	4.2ab	5.0a	1.0cd	5a	85a	35ab	201e
Mg, low	9.1bcd	.8ab	.7bc	3.7abc	4.5a	1.5ab	4ab	92a	35ab	799ab
Mg, high	8.5cd	.8ab	.7bc	3.2bc	4.3ab	1.7a	4ab	60a	36a	874a
S, low	8.1cd	.6cd	.7bc	2.6c	4.2ab	.7de	4ab	95a	25ab	350de
S, high	9.0bcd	.7bcd	.7bc	2.4c	4.2ab	.8de	4ab	98a	23b	332de

[1]C = untreated control. "Low" and "high" refer to application rates as follows: 150 and 300 kg P/ha, 100 and 200 kg K/ha, 1200 and 2400 kg Ca/ha, 75 and 150 kg Mg/ha, and 75 and 150 kg S/ha. Values are averages of 3 replications each. Within the "concentration" and "content" sections, averages followed by different letters are significantly different at $p < 0.05$.

fertilizers, especially when used at the high rate, significantly reduced the concentration of other nutrients in the foliage. Most notable reductions were in Fe, Mn, Zn, S, and Ca. Dilution by growth, changes in soil pH, and nutrient interactions were probably responsible for these reductions.

The individual fertilizers, especially when applied at the high rates, increased the content of their nutrients (that is, P, K, Ca, Mg, or S) in the foliage of the fertilized seedlings, and most increases were significant (table 4). Obviously, these gains

Table 5—Effect of fertilization on concentration of foliar nutrients of red alder seedlings grown in 2 forest soils (experiment 2)[1]

Treatment number	Nutrient									
	N	P	S	Ca	K	Mg	Cu	Fe	Zn	Mn
	Percent						*Parts per million*			
	GROVE SOIL									
1	2.34cd	0.12b	0.17b	0.83b	0.90b	0.19c	9ab	196ab	79a	1558a
2	2.24d	.12b	.16b	.99ab	.84b	.24b	7b	213a	59a	538b
3	2.42cd	.13b	.17b	.92ab	.93b	.19c	10ab	204ab	63a	787b
4	2.47bcd	.15ab	.18a	1.01a	.87b	.35a	9ab	191ab	72a	1198a
5	2.49bcd	.16a	.18a	1.05a	1.10a	.36a	9ab	181ab	90a	1546a
6	2.72ab	.17a	.19a	.89ab	1.21a	.31a	11a	199ab	80a	1315a
7	2.54abc	.16a	.18a	.93ab	1.15a	.32a	9ab	179ab	68a	1406a
8	2.77a	.17a	.19a	.91ab	1.21a	.32a	10ab	171b	87a	1300a
	WISHKAH SOIL									
1	2.40bc	0.12a	0.17b	0.42b	1.09a	0.34ab	13a	151b	132a	350a
2	2.33c	.12a	.17b	.71a	.55c	.34ab	6c	192a	68c	227a
3	2.52abc	.14a	.18ab	.75a	.82b	.29b	10b	159ab	88bc	207a
4	2.68a	.14a	.19a	.79a	.86b	.35a	11ab	145b	101ab	372a
5	2.52abc	.15a	.18ab	.82a	1.26a	.34ab	11ab	151b	123a	518a
6	2.66a	.15a	.19a	.78a	1.23a	.34ab	11ab	164ab	113ab	474a
7	2.63ab	.14a	.19a	.77a	1.25a	.33ab	10b	157ab	112ab	454a
8	2.72a	.14a	.19a	.70a	1.27a	.32ab	11ab	150b	109ab	475a

[1]Treatments: 1 = untreated control, 2 = 300 kg P/ha, 3 = 2 + 1800 kg Ca/ha, 4 = 3 + 75 kg Mg/ha, 5 = 4 + 100 kg K/ha, 6 = 5 + 75 kg S/ha, 7 = 6 + 0.1 kg Co/ha, 8 = 7 + 0.5 kg Mo/ha. Values are averages of 3 replications each. Within each soil, averages followed by different letters are significantly different at $p < 0.05$.

resulted from the uptake of the fertilizer nutrients by the seedlings. The fertilizers also increased foliar content of nutrients other than those contained in the fertilizers. Most increases were in contents of N, P, K, Ca, Mg, and S, with very few significant gains in the microelements. Fertilizers that resulted in the greatest gains in nutrient content were those containing P and Ca. These were also the most effective fertilizers for enhancing seedling growth, including dry weight of the leaves (table 2).

Experiment 2—With few exceptions, foliar-nutrient concentrations of the unfertilized trees grown in Grove soil in this experiment (table 5) were comparable to those of the Grove seedlings of experiment 1 (table 4). Presence of the forest floor on top of mineral soil in experiment 2, therefore, did not materially affect nutrient composition of the leaves. Leaves of the control seedlings grown in Wishkah soil were mostly higher in Mg, Cu, and Zn, and lower in Ca and Mn than were leaves of the Grove seedlings. The difference in foliar Ca and not Mg reflected the difference in Ca content between the

Table 6—Effect of fertilization on content of foliar nutrients of red alder seedlings grown in 2 forest soils (experiment 2)[1]

Treatment number	Nutrient									
	N	P	S	Ca	K	Mg	Cu	Fe	Zn	Mn
	Milligrams per leaf						*Micrograms per leaf*			
	GROVE SOIL									
1	6.5d	0.3c	0.5c	2.3b	2.5e	0.5c	3b	54c	22c	428b
2	8.9bcd	.5bc	.6bc	3.9a	3.3de	.9b	3b	84ab	23bc	214c
3	8.8cd	.5bc	.6bc	3.3a	3.4de	.7bc	4ab	74abc	23bc	277c
4	10.2abc	.6ab	.7ab	4.1a	3.6cde	1.5a	4ab	79ab	30abc	490ab
5	9.1bc	.6ab	.6bc	3.8a	4.1bcd	1.3a	3b	66bc	33ab	565a
6	12.3a	.7a	.9a	4.0a	5.5a	1.4a	5a	91a	36a	587a
7	10.7abc	.7a	.8ab	3.9a	4.9abc	1.3a	4ab	75ab	28abc	592a
8	11.4ab	.7a	.8ab	3.8a	5.0ab	1.3a	4ab	70abc	36a	538ab
	WISHKAH SOIL									
1	3.9c	0.2b	0.3c	0.7b	1.8c	0.5c	2a	25b	22a	58a
2	8.7a	.5a	.6a	2.7a	2.1bc	1.2a	2a	72a	25a	85a
3	6.4abc	.3ab	.4bc	1.9a	2.1bc	.7bc	2a	40b	22a	52a
4	6.5abc	.4ab	.5ab	1.9a	2.1bc	.9b	2a	35b	25a	89a
5	6.0bc	.4ab	.4bc	2.0a	3.0abc	.8bc	2a	37b	30a	124a
6	6.8ab	.4ab	.5ab	2.0a	3.2ab	.8bc	3a	42b	29a	123a
7	7.3ab	.4ab	.5ab	2.2a	3.5a	.9b	3a	44b	31a	127a
8	7.5ab	.4ab	.5ab	1.9a	3.5a	.9b	3a	41b	30a	131a

[1] Treatments: 1 = untreated control, 2 = 300 kg P/ha, 3 = 2 + 1800 kg Ca/ha, 4 = 3 + 75 kg Mg/ha, 5 = 4 + 100 kg K/ha, 6 = 5 + 75 kg S/ha, 7 = 6 + 0.1 kg Co/ha, 8 = 7 + 0.5 kg Mo/ha. Values are averages of 3 replications each. Within each soil, averages followed by different letters are significantly different at $p < 0.05$.

two soils (table 1). Differences between the two soils in content of other elements, such as N, P, K, and S (table 1), were also not reflected in foliar concentrations of those nutrients in leaves of the unfertilized seedlings of the two soils (table 5).

As in experiment 1, fertilization affected foliar nutrient concentrations of the seedlings grown in each of the two test soils (table 5). Effects were more pronounced with the macronutrients than the micronutrients. With few exceptions (Ca, Zn, and Mn), foliar nutrient concentrations of the fertilized trees did not vary much by soil. Also, in both soils, concentrations of most macronutrients became appreciably higher with the addition to the fertilizer mixture of Mg or Mg and K (that is, treatments P + Ca + Mg or P + Ca + Mg + K) and then remained essentially unchanged after additions of S, Co, and Mo fertilizers.

Unlike concentration, foliar-nutrient content of the control trees varied greatly by soil (table 6). On the average, contents of the Grove plants were higher than those of the Wishkah seedlings. This was particularly true for N, P, S, Ca, K, Cu, Fe, and Mn. Most of these differences can be attributed to the heavier leaves of the Grove plants (table 3) rather than to differences in foliar concentrations of the various nutrients (table 5).

In both soils, most fertilizers enhanced the content of foliar nutrients, although some increases were not significant. These gains, as in experiment 1, most probably resulted from parallel increases in dry-matter production (table 3) and nutrient uptake and utilization. For most nutrients, the nutrient additions resulting from fertilization were higher in the Grove than in the Wishkah plants, reflecting the heavier Grove leaves (table 3). Also, in general, nutrient content was affected most by the P + Ca + Mg + K + S treatment in the Grove soil and by the P fertilizer alone in the Wishkah soil. Again, differences in dry weight of leaves (table 3) were probably responsible for this result.

Conclusions

Results indicated that, under natural conditions, good growth of red alder cannot be expected on all forest soils. Like other plants, red alder will grow well only on sites where native soil nutrients are sufficient to meet the species' nutritional requirements for growth and development. Where native nutrients are not adequate, growth may be improved by application of the appropriate fertilizer(s). Data presented here demonstrate the potential of fertilization, especially with P fertilizer, to increase alder growth. The data also suggest caution in using combinations of fertilizers because such mixtures may materially reduce growth response.

This study was conducted with potted seedlings under lathhouse conditions, and results may not agree with those from field tests. Field experiments, therefore, are still required to test and expand upon the present findings.

Acknowledgments

The author thanks J.M. Kraft, J.E. Wilcox, and D.W. Johnson, Forestry Sciences Laboratory, Olympia, for their assistance with various phases of the study.

English Equivalents

1 hectare (ha) = 2.47 acres
1 millimeter (mm) = 0.039 inch
1 centimeter (cm) = 0.39 inch
1 liter (L) = 1.06 quarts
1 gram (g) = 0.03527 ounce
1 kilogram (kg) = 2.2046 pounds
°C = (°F - 32) /1.8

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Effects of P, K, Ca, Mg, S, Co, and Mo fertilizers on growth and foliar nutrients of red alder seedlings potted in Grove, Bunker, and Wishkah forest soils were determined. Growth in Grove soil was stimulated most by P, Ca, and P + Ca + Mg + K + S. Growth in Bunker soil was improved only by P. In Wishkah soil, best growth was obtained when P was used alone; all fertilizer mixtures produced less growth. Results indicated the potential of fertilizer to increase alder production and suggested caution in using fertilizer mixtures because they may materially reduce growth response.

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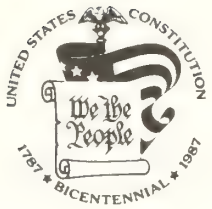

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PNW-RP-376

Levels-of-Growing-Stock Cooperative Study in Douglas-Fir: Report No. 9 —

Some Comparisons of DFSIM Estimates With Growth in the Levels-of-Growing-Stock Study

Robert O. Curtis

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Levels-of-growing-stock study treatment schedule, showing percent of gross basal area increment of control plot to be retained in growing stock

	Treatment							
Thinning	1	2	3	4	5	6	7	8
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Background

Public and private agencies are cooperating in a study of eight thinning regimes in young Douglas-fir stands. Regimes differ in the amount of basal area allowed to accrue in growing stock at each successive thinning. All regimes start with a common level-of-growing-stock established by a conditioning thinning.

Thinning interval is controlled by height growth of crop trees, and a single type of thinning is prescribed.

Nine study areas, each involving three completely random replications of each thinning regime and an unthinned control, have been established in western Oregon and Washington, U.S.A., and on Vancouver Island, British Columbia, Canada. Site quality of these areas varies from I through IV.

LEVELS-OF-GROWING-STOCK COOPERATIVE STUDY IN DOUGLAS-FIR:

Report No. 9—Some Comparisons of DFSIM Estimates With Growth in the Levels-of-Growing-Stock Study

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USDA Forest Service Research Paper PNW-RP-376
Pacific Northwest Research Station
Portland, Oregon 1987

Abstract

Curtis, Robert O. 1987. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 9--Some comparisons of DFSIM estimates with growth in the levels-of-growing-stock study. Res. Pap. PNW-RP-376. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 34 p.

Initial stand statistics for the levels-of-growing-stock study installations were projected by the Douglas-fir stand simulation program (DFSIM) over the available periods of observation. Estimates were compared with observed volume and basal area growth, diameter change, and mortality. Overall agreement was reasonably good, although results indicate some biases and a need for revision of the upper density limit in the DFSIM program.

KEYWORDS: Simulation, projections (stand), model validation, statistics (stand), growing stock (-increment/yield, Douglas-fir, *Pseudotsuga menziesii).*

Summary

Initial stand statistics for the levels-of-growing-stock (LOGS) study installations were projected by the Douglas-fir stand simulation program (DFSIM) over the available periods of observation. Thinnings were simulated by use of observed top height trends, actual residual basal areas, and actual ratios of cut tree diameters to stand diameter before cutting (d/D). Estimates were compared with observed gross and net volumes and basal area growth, net change in quadratic mean diameter, and change in number of trees. Although the LOGS installations include regimes quite different from those in most of the data used to construct DFSIM, overall agreement was reasonably good. Results indicate some density-related bias in the thinned stands and a need for revision in the method used to control the maximum density in the DFSIM program and in the associated mortality estimates.

Other LOGS (Levels-of-Growing-Stock) Reports

Williamson, Richard L.; Staebler, George R. 1965. A cooperative level-of-growing-stock study in Douglas-fir. Portland, OR: U.S.Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.
Describes purpose and scope of a cooperative study which is investigating the relative merits of eight different thinning regimes. Main features of six study areas installed since 1961 in young stands are also summarized.

Williamson, Richard L.; Staebler, George R. 1971. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 1—Description of study and existing study areas. Res. Pap. PNW-111. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.
Thinning regimes in young Douglas-fir stands are described. Some characteristics of individual study areas established by cooperating public and private agencies are discussed.

Bell, John F.; Berg, Alan B. 1972. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 2—The Hoskins study, 1963-1970. Res. Pap. PNW-130. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 19 p.
A calibration thinning and the first treatment thinning in a 20-year-old Douglas-fir stand at Hoskins, Oregon, are described. Data tabulated for the first 7 years of management show that growth changes in the thinned stands were greater than anticipated.

Diggle, P.K. 1972. The levels-of-growing-stock cooperative study in Douglas-fir in British Columbia (Report No. 3, Cooperative L.O.G.S. study series). Inf. Rep. BC-X-66. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre. 46 p.

Williamson, Richard L. 1976. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 4—Rocky Brook, Stampede Creek, and Iron Creek. Res. Pap. PNW-210. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 39 p.
The USDA Forest Service maintains three of nine installations in a regional, cooperative study of influences of levels of growing stock (LOGS) on stand growth. The effects of calibration thinnings are described for the three areas. Results of first treatment thinning are described for one area.

Berg, Alan B.; Bell, John F.1979. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 5—The Hoskins study, 1963-1975. Res. Pap. PNW-257. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 29 p.
The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

Introduction

The Douglas-fir stand simulator DFSIM (Curtis and others 1981, 1982) is widely used for coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) in the Pacific Northwest. Limited comparisons with other data sets and with other simulators (Mitchell 1986, Mitchell and Cameron 1985) indicate that DFSIM estimates are in reasonable overall agreement with growth observed in several data sets, and with predictions from some other stand simulators.

Management options for new plantations and for intensively managed young stands, however, include regimes that are radically different from past practice and often outside the range of the data used in constructing DFSIM. The basic data used for DFSIM were mostly from natural stands. The data base available (1974) for this and alternate models contained relatively little information from stands with wide initial spacing, from older plantations, from stands with systematic thinning begun at an early age, or from stands with repeated fertilization. There are questions concerning the applicability of the current version of DFSIM to stands that have had early stocking control followed by systematic repeated thinning, and to stands established or maintained at much lower densities than was common practice in the past.

Preliminary results of some work done under the Forest Intensified Research (FIR) program in southwest Oregon[1] indicate that DFSIM slightly underestimates volume growth and overestimates mortality for the small research plots used in these fertilizer and fertilizer-thinning studies, and that these selected uniform stands frequently attain higher densities than predicted by DFSIM. A greater cause for concern is a tendency to underestimate response to thinning, compared with the preliminary analyses for southwest Oregon.

The levels-of-growing-stock (LOGS) study (Curtis and Marshall 1986) provides an extensive set of consistent, high-quality data for stands with early stocking control, subsequent intensive systematic thinning, a range of growing stock that includes much lower levels than were common in the past, and an extended period of observation. Because the LOGS studies use small, uniform plots and closely controlled treatments, the plots probably approximate the upper limit of growth for the specified regimes.

The LOGS regimes do not directly represent practical management options, and comparisons with LOGS data cannot provide a complete answer to the question of DFSIM's applicability to future intensively managed stands. Comparisons of observed growth from the LOGS study with DFSIM predictions, however, should indicate the model's ability to predict stand development for these regimes and may indicate the nature and magnitude of changes needed.

This report presents comparisons of DFSIM estimates with actual growth on the LOGS installations. Similar comparisons are briefly noted for two other available data sets representing plantations with a wide range in initial stocking.

The LOGS Data

The LOGS data have been described in detail by Curtis and Marshall (l986) and previous authors (Arnott and Beddows 1981; Bell and Berg 1972; Berg and Bell 1979; Diggle 1972; Williamson 1976; Williamson and Curtis 1984; Williamson and Staebler 1965, 1971). Some additional data from recent measurements at the Stampede Creek, Iron Creek, and Clemons studies, not used in previous analyses, were also available.

[1] Data and analyses (study C-53) on file at Forestry Sciences Laboratory, Olympia, WA.

The LOGS studies include eight thinning treatments plus an untreated control treatment. There are three 1/5-acre plots in each treatment (four control plots in the Skykomish study) in a completely random arrangement. The stands were selected for initial uniformity and had had little competition before the study was established, as was shown by live crowns extending over most of the bole. In most installations the stand was 20-40 feet in height at the time of establishment, slightly taller in some instances.

The thinned plots received an initial calibration thinning that reduced all treated plots in an installation to a single density level, usually about 400 stems per acre. Subsequent treatment thinnings, made at intervals of 10 feet of height growth, retained specified percentages of the gross basal area growth observed on the controls (table, inside front cover). Treatments 1, 3, 5, 7 (the "fixed" treatments) retained 10, 30, 50, and 70 percent, respectively; treatments 2, 4, 6, and 8 retained percentages that varied for successive treatment thinnings.

The "calibration period" is the period from the calibration thinning to the first treatment thinning. Subsequent periods are referred to as "treatment periods."

The available data consisted of the data for the calibration period at all installations, plus data for the following numbers of treatment periods by installation:

Site class	Installation	Treatment periods
II	Iron Creek	4
	Clemons	5
	Hoskins	5
	Francis	4
	Skykomish	5
III	Stampede	2
	Sayward	2
IV	Rocky Brook	2
	Shawnigan	1

Although early measurements (before 1974) from several LOGS installations were included in the data used to construct DFSIM, these were a small part of the data and of the range of densities now available and constituted a very minor portion of the total DFSIM data base. The LOGS data are almost--but not quite--an independent data set.

Methods

Simulation estimates can be compared with observed growth in many ways. A limited number of comparisons must be chosen that appear meaningful in terms of the objective of primary concern and are consistent with the limitations of the data available.

Comparisons with a data set such as LOGS, limited in size and geographic range as well as in the range of initial conditions and treatments covered, cannot give a generally applicable estimate of overall bias and error. The objective of these comparisons was not to produce such an estimate, but to look for features of simulator behavior inconsistent with this data set and possibly indicative of a need to modify the simulator. Therefore, these comparisons rely primarily on simple averages and graphic comparisons rather than on formal statistical tests, and results are suggestive rather than conclusive

Comparisons must take into account the structure of the simulator, so that differences between estimates and observation can be related to specific characteristics of the model.

Height Growth

Height growth is one of the major driving variables in DFSIM, and the simulator provides alternate height growth estimation procedures. Regional height growth curves generate heights and height growth, given age and site index; however, an option is provided that allows substitution of local height growth trends, if known. Three procedures are possible:

1. Use the regional curves corresponding to the site estimate based on height at the beginning of the simulation.

   This is the most realistic procedure if the objective is projection of existing stands of intermediate age. This method will give very inaccurate estimates when applied to young stands because site index estimates made in young stands are very unreliable.

2. Use the regional curve corresponding to the site estimate based on the age nearest the index age.

   This is reasonable if the objective is comparison of regimes on land of known site index, with no knowledge of the local height growth trend.

3. Use observed height growth trends for individual stand.

   This will give the most accurate estimates but requires information that is often not available.

Because DFSIM already provides for modifying the height growth curve when the necessary information is available, questions primarily concern the performance of the routines estimating diameter growth, basal area growth, volume growth, and mortality. Because procedure 3 eliminates considerable extraneous variation and because the information needed to apply it is available for the LOGS data, it was adopted for these comparisons.

Observed top height (H40) trends were smoothed to eliminate minor irregularities caused in part by measurement error and to provide height growth curves "correct" for the given location. A regression, of the form $H = a + b(age) + c(age)^2$, was fitted to the estimates of top height for successive ages. The resulting curve, specific to the individual stand, was used as the "observed height trend" in DFSIM projections.

Grouping of Plots

Comparisons used means of the three plots in each treatment within each installation. Only treatments 1, 3, 5, 7 ("fixed percentage" thinning treatments) and the control were included. These restrictions were adopted to simplify computations and comparisons and because the "variable percentage" treatments do not clearly correspond to readily interpretable differences in stand density.

Management Regime

Management regime must be accounted for in the simulations. Because basal area was the primary thinning control in the LOGS studies, it seemed reasonable to use basal area in combination with the d/D ratio (ratio of quadratic mean diameter of trees

cut to quadratic mean diameter of stand before cutting). Therefore, the principal comparisons were made using (1) observed height trends, smoothed as above; and (2) actual number of trees and basal area at the beginning of the simulation. Each successive thinning was made at the same age as in the corresponding LOGS data; d/D ratios and residual basal areas were identical to those in the corresponding actual thinning. Thus, deviations of projections from the observed LOGS statistics are the result of cumulative differences in basal area growth, volume growth, mortality, and diameter growth.

Projection Routines

DFSIM uses different projection routines for the juvenile stand (quadratic mean diameter (D) less than 5.6 inches) and the main stand (quadratic mean diameter 5.6 inches or larger), and comparisons must be subdivided accordingly.

Comparison Groups

The comparisons with LOGS data were divided into four groups:

1. Thinned, treatment periods, main stand routine (D equal to or greater than 5.6 inches).

2. Thinned, calibration period. At all installations except Stampede Creek, this includes only the juvenile stand routine.

3. Control, main stand routine (D equal to or greater than 5.6 inches).

4. Control, juvenile stand (D less than 5.6 inches).

Comparisons for LOGS Thinned Treatments

Analysis

Treatment periods (main stand routine).—Beginning with the actual number of trees and basal area at the beginning of the first treatment period in which diameter was 5.6 inches or larger, stands were projected to the age of the most recent measurement, separately for each thinning treatment, by installation. The resulting projection periods in years are shown in table 1.

Thinning treatments were simulated by reducing the stand to the same residual basal area as the corresponding LOGS treatment, with d/D ratio equal to that in the actual LOGS thinning. Numbers of trees and diameters were not controlled after the simulation was begun, which allowed errors to accumulate in a manner similar to that in practical applications of the simulator.

An adjusted age was used for the Francis study, calculated as age at breast height (b.h.) plus 7 years, rather than recorded stand age. This adjustment was made because DFSIM uses in its calculations an age at b.h. calculated as total age minus 7 years for site II. Adjusted ages are shown in the tables.

The resulting estimates of gross volume growth, gross basal area growth, net change in stand average diameter and number of trees, and cumulative mortality in volume and basal area are shown in tables 1 through 4, together with corresponding actual values from the LOGS data. Actual values are graphically compared with DFSIM estimates in figures 1 through 7.

Table 1--Comparison of observed gross volume growth and mortality with DFSIM estimates for main stand routine projections for thinning treatments 1, 3, 5, and 7

Site	Installation	Projection period	Treatment	Gross volume increment			Mortality volume		Ratio, mortality volume/gross volume increment	
				Observed	DFSIM	Observed/DFSIM	Observed	DFSIM	Observed	DFSIM
		years		ft^3/acre			ft^3/acre			
II	Iron Creek	14	1	2,831	3,094	0.92	153	15	0.054	0.005
			3	3,800	3,686	1.03	120	18	.032	.005
			5	4,573	4,371	1.05	88	46	.019	.011
			7	5,103	4,718	1.08	211	122	.041	.026
	Hoskins	17	1	4,607	4,496	1.02	0	22	0	.005
			3	5,860	5,512	1.06	0	28	0	.005
			5	7,217	6,205	1.16	125	122	.017	.020
			7	8,130	6,524	1.25	83	221	.010	.034
	Clemons	14	1	2,512	2,510	1.00	10	12	.004	.005
			3	3,269	3,385	.97	30	16	.009	.005
			5	3,562	3,401	1.05	234	26	.066	.008
			7	3,804	3,739	1.02	152	93	.040	.025
	Francis	16	1	2,938	3,227	.91	11	15	.004	.005
			3	4,186	4,391	.95	10	21	.002	.005
			5	5,563	5,433	1.02	159	44	.029	.008
			7	6,184	5,902	1.05	10	125	.002	.021
	Skykomish	18	1	4,369	4,100	1.07	13	21	.003	.005
			3	5,477	4,624	1.18	46	23	.008	.005
			5	6,673	5,365	1.24	48	115	.007	.021
			7	7,306	5,854	1.25	160	250	.022	.043
III	Stampede Creek	10	1	2,133	1,898	1.12	1	9	0	.005
			3	2,322	2,253	1.03	2	12	0	.005
			5	2,372	2,211	1.07	0	26	0	.012
			7	2,692	2,515	1.07	5	51	.002	.020
	Sayward	8	1	1,319	1,531	.86	0	7	0	.005
			3	1,533	1,708	.90	0	8	0	.005
			5	1,721	1,975	.87	0	9	0	.005
			7	1,952	1,926	1.01	0	14	0	.007
IV	Rocky Brook	13	1	1,530	1,874	.82	11	8	.007	.004
			3	1,728	2,189	.79	93	9	.054	.004
			5	1,868	2,331	.80	68	21	.036	.009
			7	2,409	2,644	.91	62	48	.026	.018
	Shawnigan	6	1	674	786	.86	0	3	0	.004
			3	813	870	.93	0	4	0	.005
			5	858	944	.91	4	4	.005	.004
			7	900	891	1.01	21	6	.023	.007

Table 2--Comparison of observed gross basal area growth and mortality with DFSIM estimates for main stand routine projections for thinning treatments 1, 3, 5, and 7

Site	Installation	Projection period	Treatment	Gross basal area increment			Basal area mortality		Basal area mortality/ gross basal area increment	
				Observed	DFSIM	Observed/DFSIM	Observed	DFSIM	Observed	DFSIM
		years		ft^2/acre			ft^2/acre			
II	Iron Creek	14	1	85.5	95.5	0.90	7.1	0.6	0.083	0.006
			3	104.3	106.3	.98	5.4	.7	.051	.007
			5	115.8	107.1	1.08	3.6	1.6	.031	.015
			7	125.6	108.4	1.16	8.7	4.1	.069	.038
	Hoskins	17	1	125.1	122.4	1.02	0	.8	0	.007
			3	147.4	135.6	1.09	0	1.0	0	.007
			5	170.0	131.9	1.29	3.8	3.7	.022	.028
			7	182.4	130.7	1.40	2.6	6.6	.014	.050
	Clemons	14	1	66.8	71.4	.94	.4	.4	.006	.006
			3	80.4	85.7	.94	1.0	.6	.013	.007
			5	93.7	86.2	1.09	12.1	.9	.129	.010
			7	86.2	84.0	1.03	5.6	3.0	.064	.036
	Francis	16	1	92.1	108.5	.85	.6	.6	.007	.006
			3	122.3	132.5	.92	.6	.8	.004	.006
			5	143.7	140.5	1.02	6.3	1.5	.044	.011
			7	169.4	146.7	1.15	.5	4.5	.003	.031
	Skykomish	18	1	100.4	93.1	1.08	.5	.6	.005	.006
			3	128.5	101.2	1.27	1.4	.7	.011	.007
			5	137.6	102.4	1.34	1.8	3.1	.013	.030
			7	156.7	109.6	1.43	4.6	6.8	.029	.062
III	Stampede Creek	10	1	51.8	45.3	1.14	.1	.3	.002	.007
			3	54.5	50.0	1.09	.1	.4	.002	.008
			5	55.0	46.0	1.20	0	.8	0	.017
			7	57.8	48.5	1.19	1.1	1.5	.019	.031
	Sayward	8	1	41.1	51.4	.80	0	.3	0	.006
			3	47.2	55.6	.85	0	.3	0	.005
			5	51.4	61.0	.84	0	.4	0	.007
			7	54.2	55.2	.98	0	.6	0	.011
IV	Rocky Brook	13	1	53.4	61.5	.87	.6	.2	.012	.003
			3	58.8	70.2	.84	4.9	.4	.083	.006
			5	63.8	70.1	.91	3.9	.9	.061	.013
			7	76.7	73.7	.04	3.2	1.9	.042	.026
	Shawnigan	6	1	22.3	28.2	.79	0	.2	0	.007
			3	25.0	30.6	.82	0	.2	0	.007
			5	27.7	32.6	.85	.2	.2	.008	.006
			7	29.3	29.5	.99	1.0	.3	.033	.010

Table 3--Net change in quadratic mean diameter (D) for main stand routine projections for thinning treatments 1, 3, 5, and 7

Site	Installation	Projection period	Treatment	Initial D, before cut	Final D, before cut		Net diameter increment		Net diameter increment: ratio, Observed / DFSIM
					Observed	DFSIM	Observed	DFSIM	
		years		inches					
II	Iron Creek	14	1	6.37	13.80	14.86	7.43	8.49	0.88
			3	6.56	12.61	12.22	6.05	5.66	1.07
			5	6.69	11.92	11.44	5.23	4.75	1.10
			7	6.65	11.17	11.04	4.52	4.39	1.03
	Hoskins	17	1	6.68	17.79	17.30	11.11	10.62	1.05
			3	6.75	15.48	14.62	8.73	7.87	1.11
			5	6.59	13.96	12.12	7.37	5.53	1.33
			7	6.93	13.47	11.63	6.54	4.70	1.39
	Clemons	14	1	7.09	14.30	14.65	7.21	7.56	.95
			3	6.85	12.87	13.44	6.02	6.59	.91
			5	6.55	10.85	10.40	4.30	3.85	1.12
			7	6.54	9.86	9.84	3.32	3.30	1.01
	Francis	16	1	6.75	16.69	19.13	9.94	12.38	.80
			3	6.90	14.95	15.62	8.05	8.71	.92
			5	6.74	12.84	12.73	6.10	5.99	1.02
			7	6.56	11.66	11.29	5.10	4.73	1.08
	Skykomish	18	1	6.87	17.57	16.34	10.70	9.47	1.13
			3	6.45	15.77	13.22	9.32	6.77	1.38
			5	6.54	13.13	11.32	6.59	4.78	1.38
			7	6.87	13.16	11.49	6.29	4.62	1.36
III	Stampede Creek	10	1	7.86	11.91	11.49	4.05	3.63	1.12
			3	7.95	11.89	11.52	3.94	3.57	1.10
			5	7.97	10.76	10.42	2.79	2.45	1.14
			7	8.04	10.66	10.22	2.62	2.18	1.20
	Sayward	8	1	6.06	8.98	9.66	2.92	3.60	.81
			3	6.22	8.68	9.29	2.46	3.07	.80
			5	6.33	8.76	9.31	2.43	2.98	.82
			7	6.31	8.47	8.55	2.16	2.24	.96
IV	Rocky Brook	13	1	5.31	9.61	10.09	4.30	4.78	.90
			3	5.33	8.38	8.81	3.05	3.48	.88
			5	5.22	7.96	8.11	2.74	2.89	.95
			7	5.27	8.11	8.06	2.84	2.79	1.02
	Shawnigan	6	1	5.80	7.53	7.86	1.73	2.06	.84
			3	5.93	7.38	7.68	1.45	1.75	.83
			5	5.97	7.35	7.58	1.38	1.61	.86
			7	5.82	6.97	6.99	1.15	1.17	.98

Table 4--Net change in number of trees for main stand routine projections for thinning treatments 1, 3, 5, and 7

Site	Installation	Projection period	Treatment	Initial number, before cut	Final number, before cut		Net change in number of trees		Final number of trees: ratio, Observed / DFSIM
					Observed	DFSIM	Observed	DFSIM	
		years		number per acre					
II	Iron Creek	14	1	343	77	72	266	271	1.07
			3	340	145	145	195	195	1.00
			5	338	207	225	131	113	.92
			7	347	283	305	64	42	.93
	Hoskins	17	1	352	52	56	300	296	.93
			3	342	102	114	240	228	.90
			5	363	165	215	198	148	.77
			7	328	223	283	105	45	.79
	Clemons	14	1	235	57	58	178	177	.98
			3	282	105	100	177	182	1.05
			5	332	188	215	144	117	.87
			7	365	283	288	82	77	.98
	Francis	16	1	235	45	38	190	197	1.18
			3	243	97	92	146	151	1.05
			5	340	185	187	155	153	.99
			7	400	292	299	108	101	.98
	Skykomish	18	1	338	50	59	288	279	.85
			3	375	92	126	283	249	.73
			5	362	172	218	190	144	.79
			7	348	205	247	143	101	.83
III	Stampede Creek	10	1	292	130	133	162	159	.98
			3	287	150	157	137	130	.96
			5	282	203	207	79	75	.98
			7	277	228	239	49	38	.95
	Sayward	8	1	355	165	155	190	200	1.06
			3	355	218	204	137	151	1.07
			5	355	252	238	103	117	1.06
			7	355	310	307	45	48	1.01
IV	Rocky Brook	13	1	232	130	135	102	97	.96
			3	323	228	235	95	88	.97
			5	368	318	325	50	43	.98
			7	392	370	370	22	22	1.00
	Shawnigan	6	1	375	215	214	160	161	1.00
			3	373	260	256	113	117	1.02
			5	375	297	295	78	80	1.01
			7	375	362	364	13	11	1.00

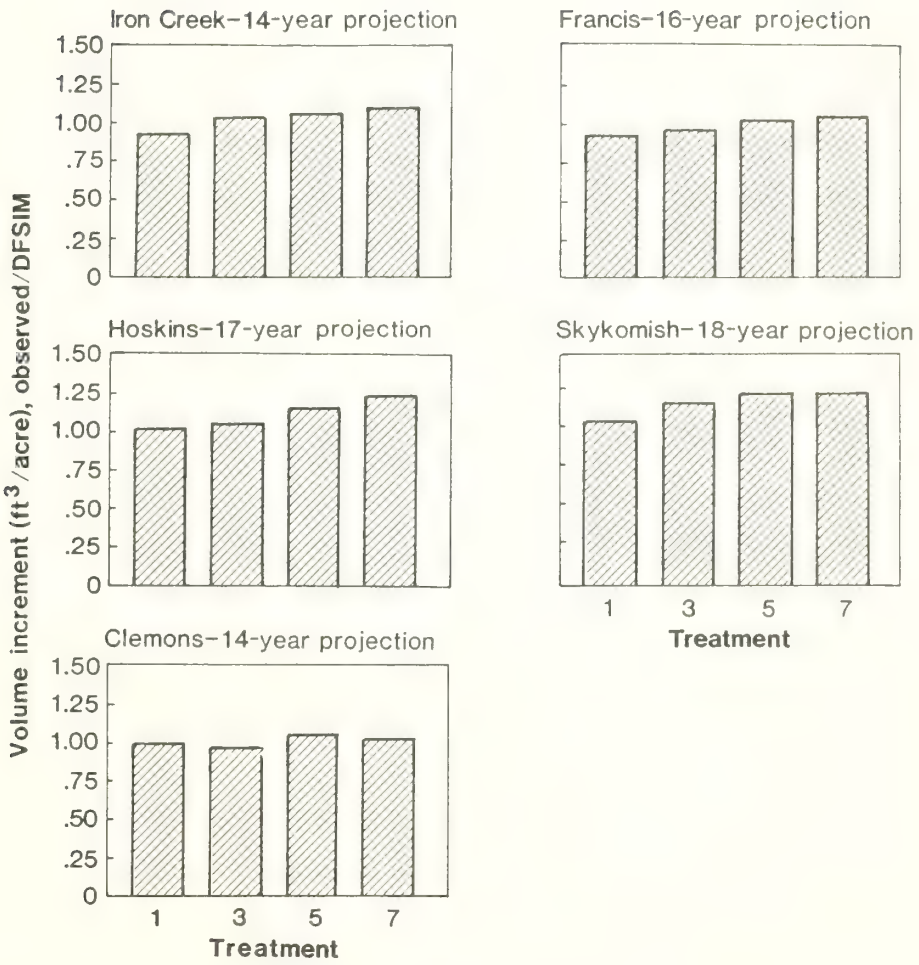

Figure 1—Ratios of observed gross volume growth to DFSIM estimates, by treatment within installation, on thinned plots, main stand routine. A. Site II installations.

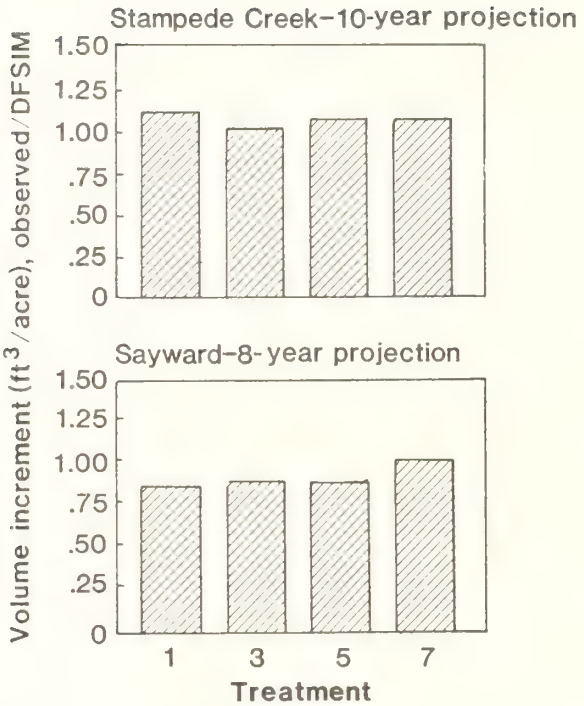

Figure 1 (continued)—B. Site III installations.

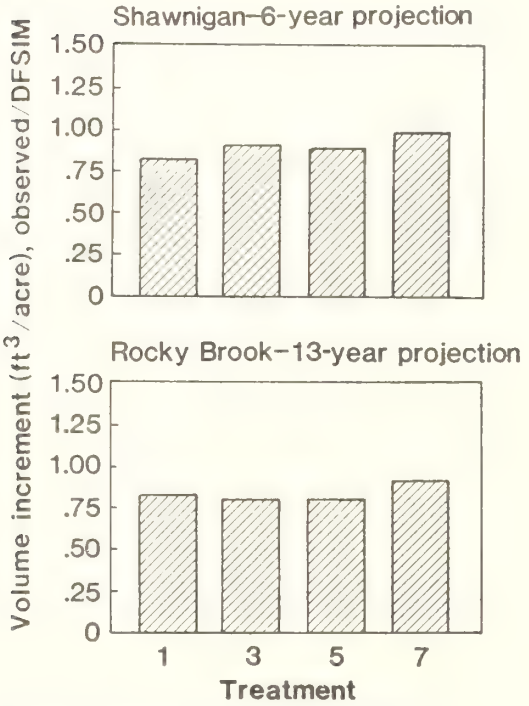

Figure 1 (continued)—C. Site IV installations.

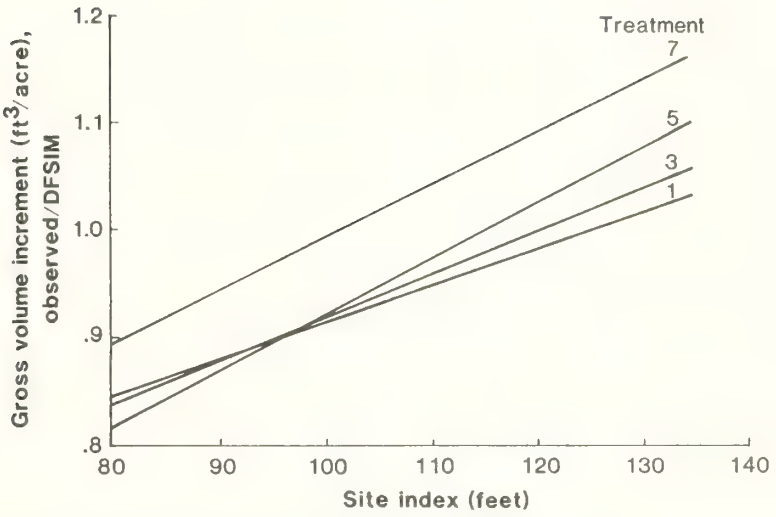

Figure 2—Regressions of ratios of observed/DFSIM gross volume increment (table 1) on site index, fit to values for eight installations (excluding Skykomish), by treatment.

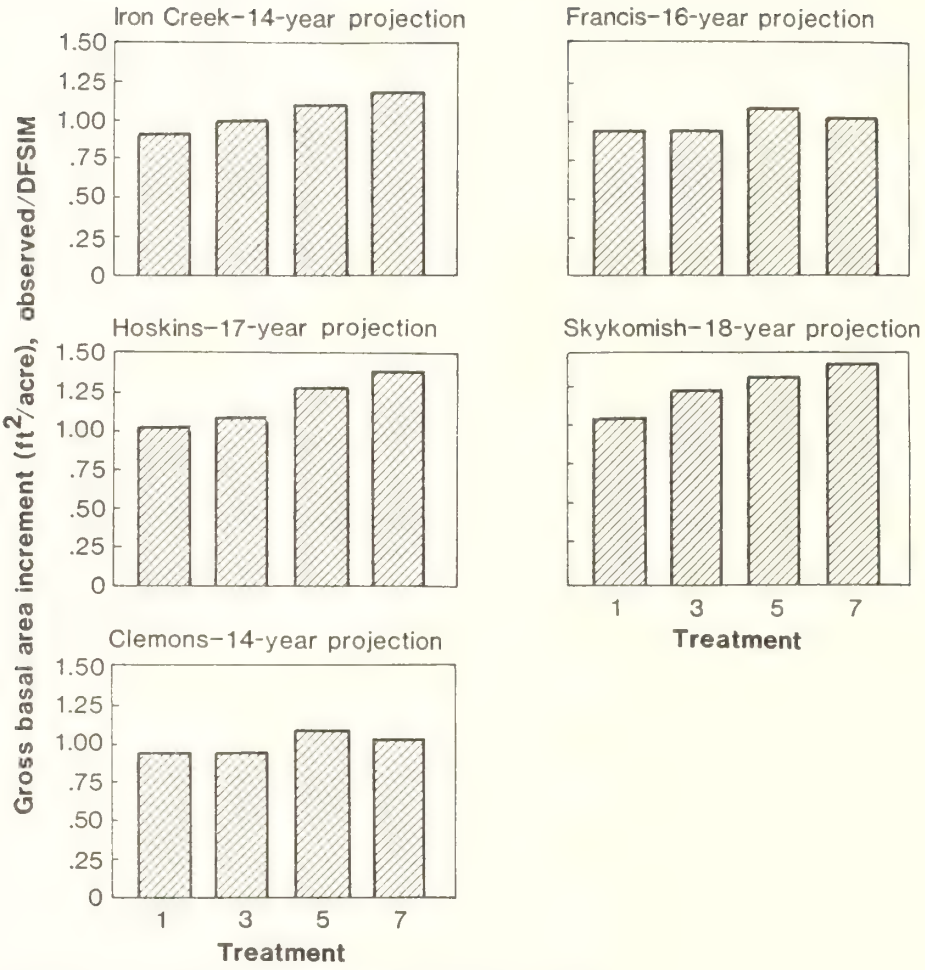

Figure 3—Ratios of observed gross basal area growth to DFSIM estimates, by treatment within installation, thinned plots, main stand routine. A. Site II installations.

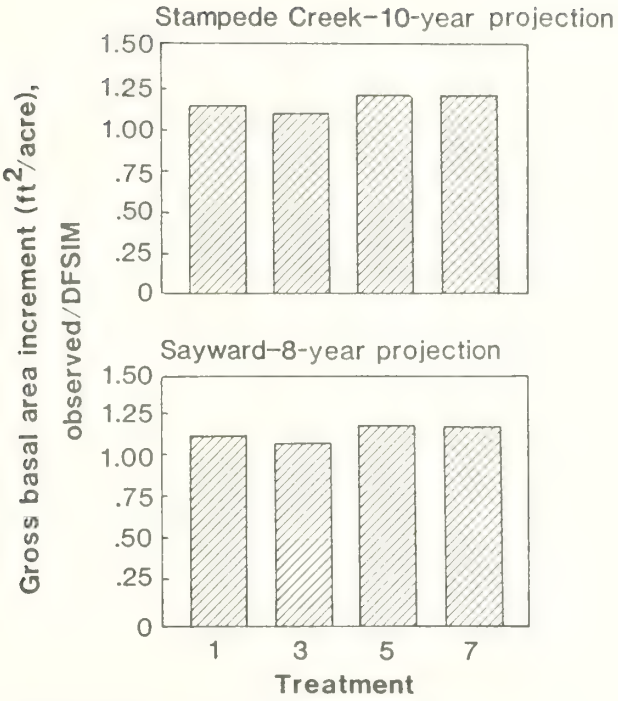

Figure 3 (continued)—B. Site III installations.

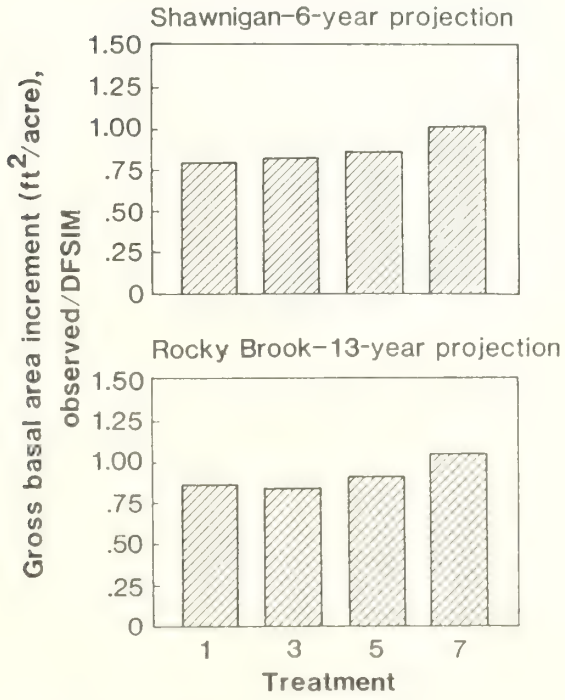

Figure 3 (continued)—C. Site IV installations.

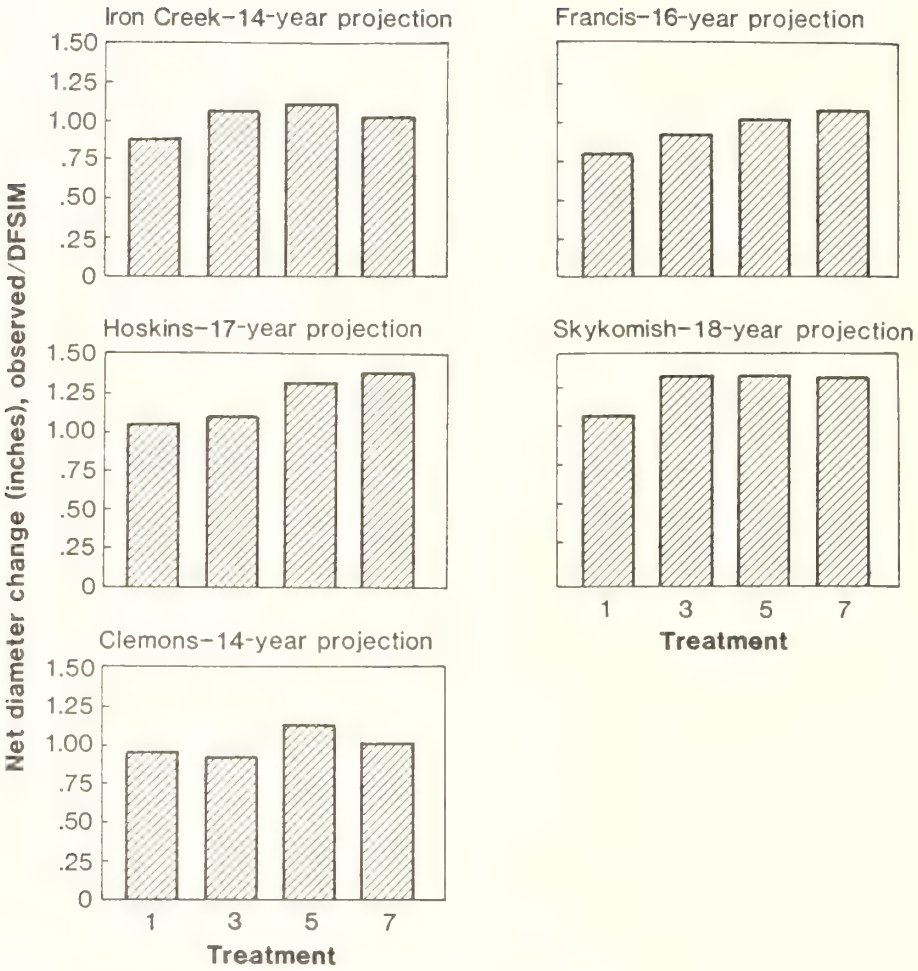

Figure 4—Ratios of observed net diameter change to DFSIM estimates, by treatment within installations, thinned plots, main stand routine. A. Site II installations.

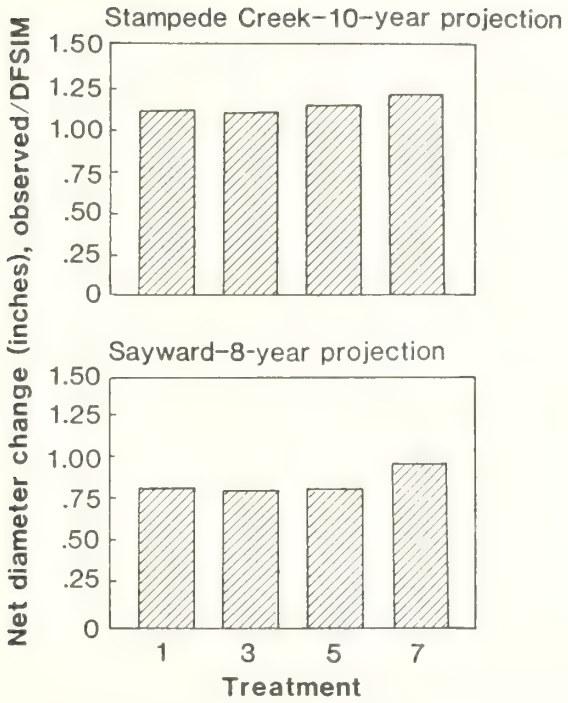

Figure 4 (continued)—B. Site III installations.

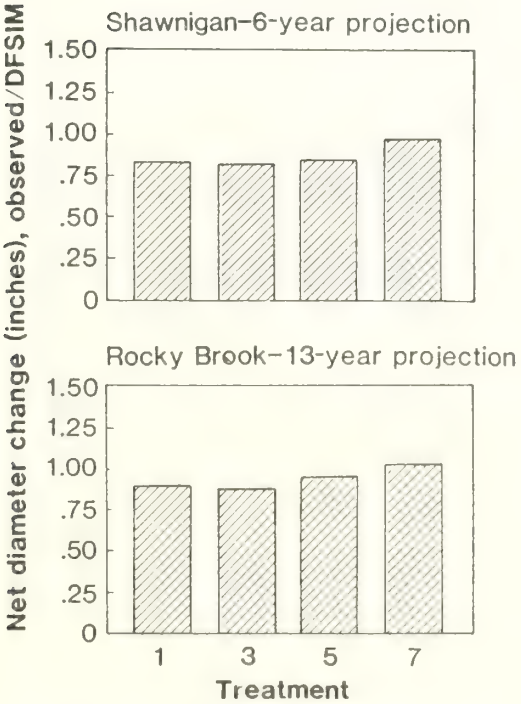

Figure 4 (continued)—C. Site IV installations.

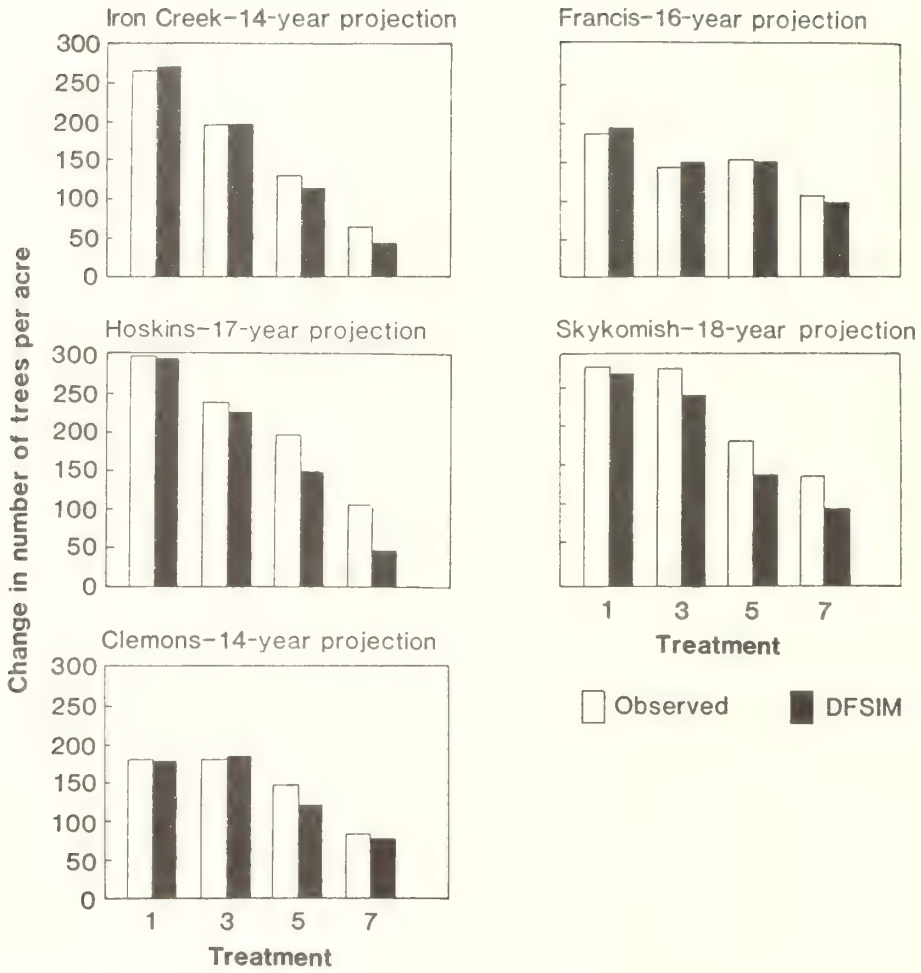

Figure 5—Comparison of observed net change in number of trees with DFSIM estimates, by treatment within installations, thinned plots, main stand routine. A. Site II installations.

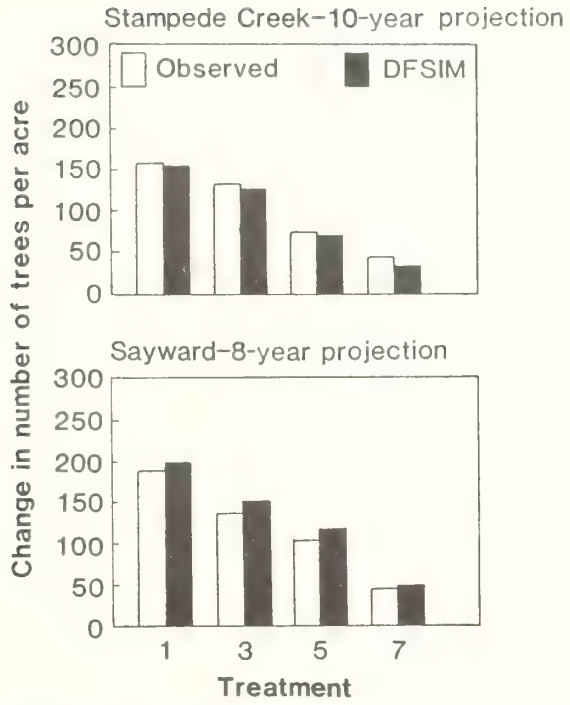

Figure 5 (continued)—B. Site III installations.

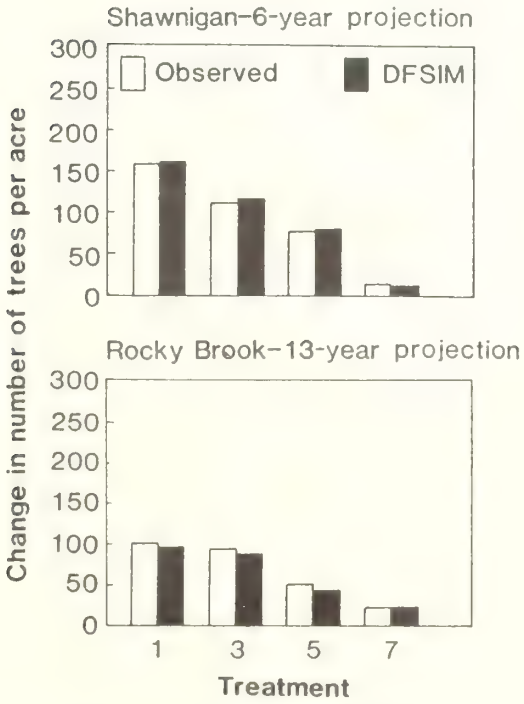

Figure 5 (continued)—C. Site IV installations.

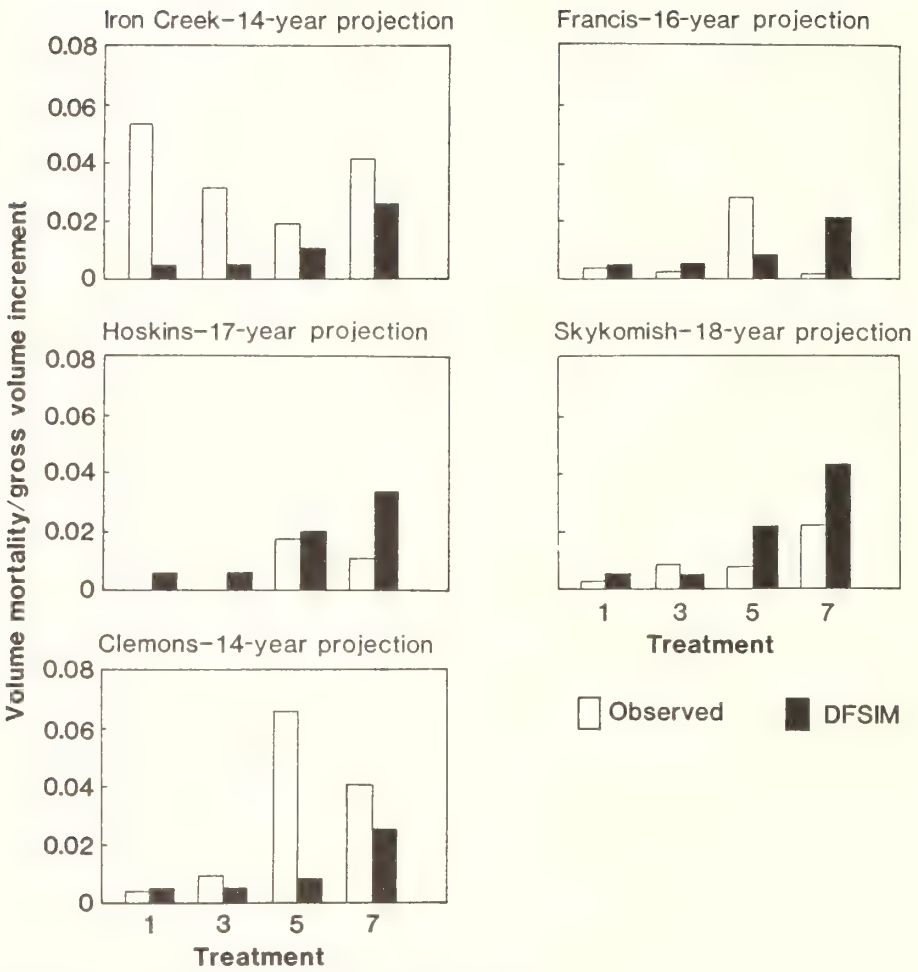

Figure 6—Ratios of volume of mortality to gross growth for observed values and for DFSIM, by treatment within installations, thinned plots, main stand routine. A. Site II installations.

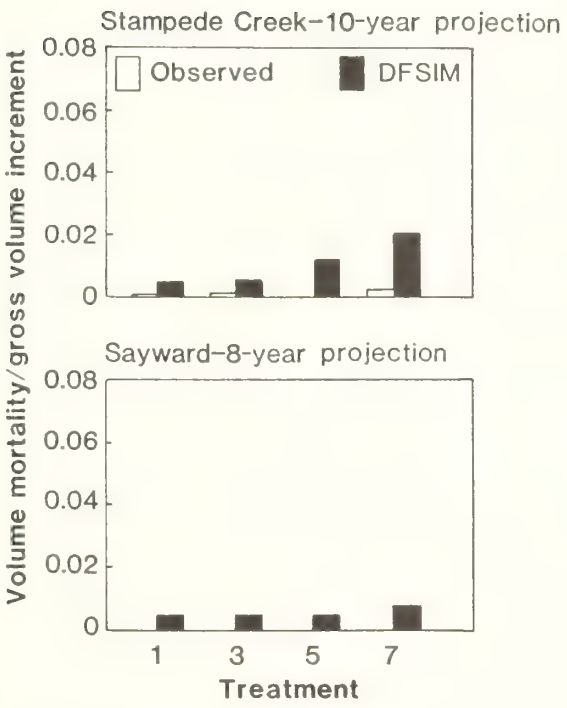

Figure 6 (continued)—B. Site III installations.

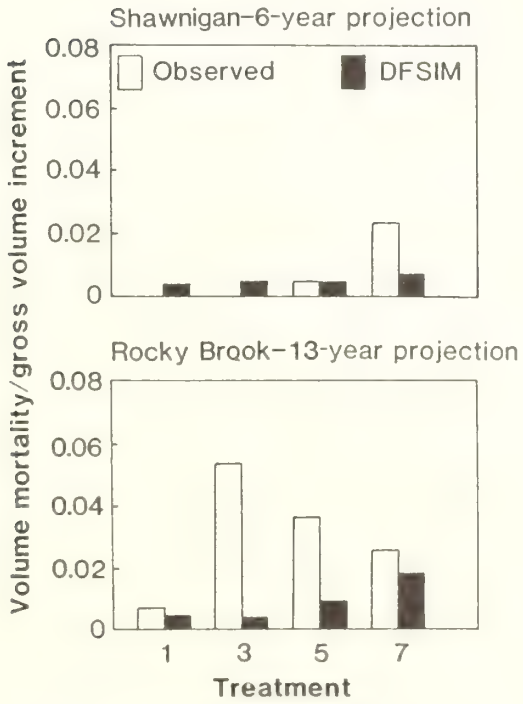

Figure 6 (continued)—C. Site IV installations.

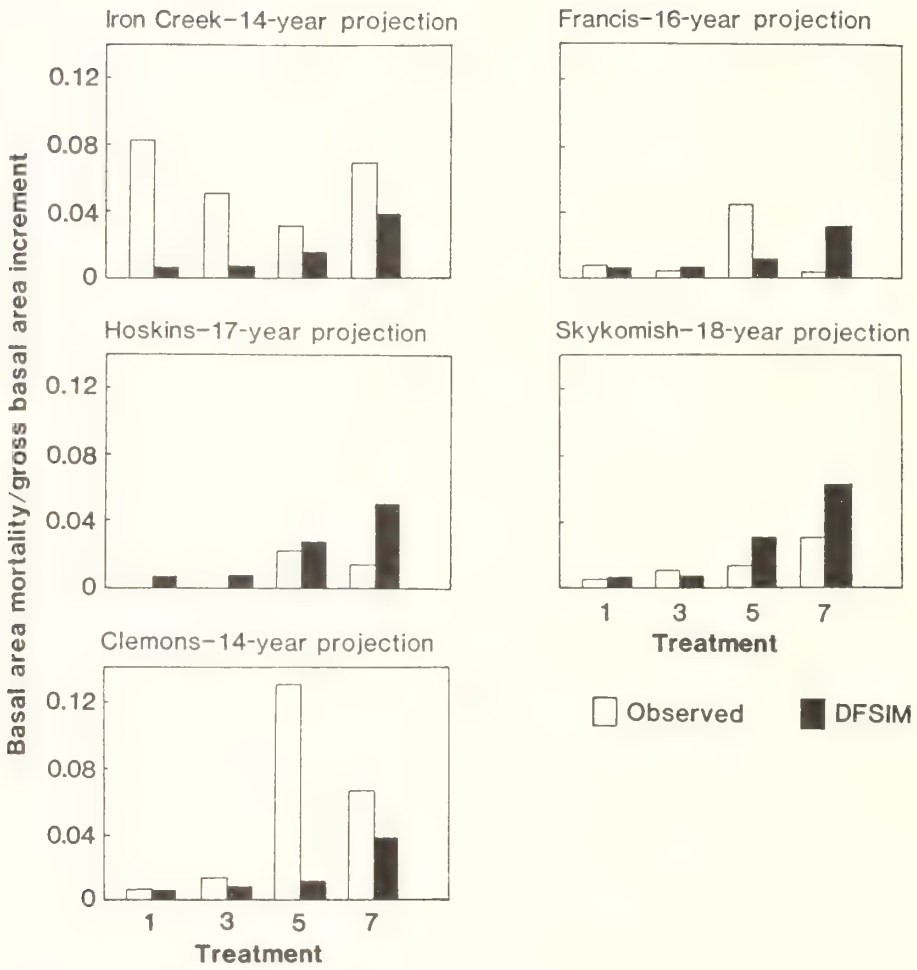

Figure 7—Ratios of basal area mortality to gross growth for observed values and for DFSIM estimates, by treatment within installation, thinned plots, main stand routine. A. Site II installations.

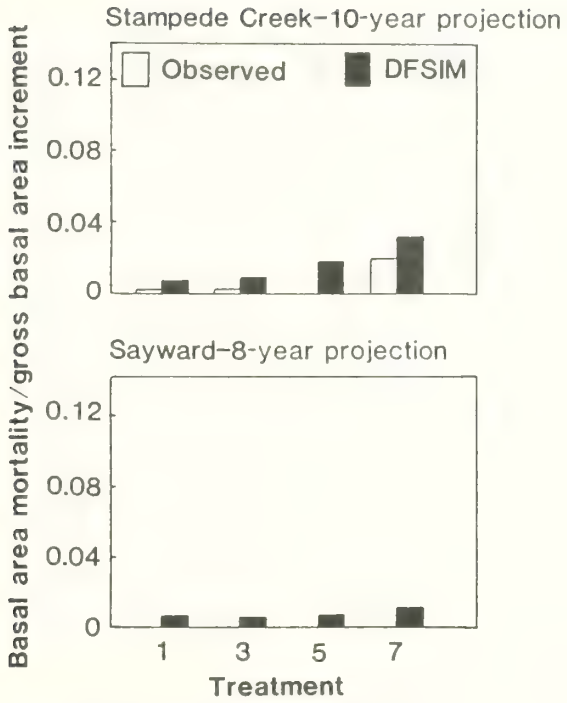

Figure 7 (continued)—B. Site III installations.

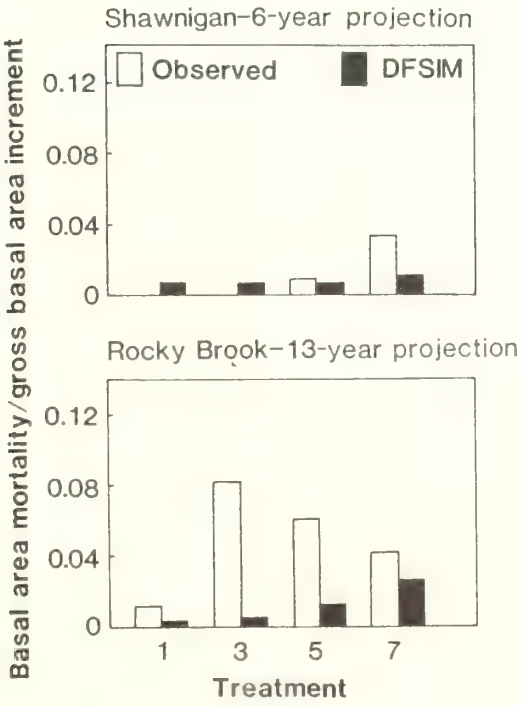

Figure 7 (continued)—C. Site IV installations.

Calibration period (juvenile stand).—A parallel series of projections was made for the calibration period only. Because all thinning treatments were treated alike at the calibration cut, results are shown as means for all thinning treatments, by installation (table 5 and figs. 8-10).

Table 5--Comparison of thinned plot mean increments with DFSIM estimates for calibration period only, thinning treatments 1, 3, 5, and 7 combined

Site	Installation	Projection period ages	Ratios of net increment: Observed/DFSIM		
			Volume	Basal area	D.b.h.
		years			
II	Iron Creek	19-23	0.97	0.98	1.04
	Clemons	19-22	.94	.92	.92
	Hoskins	20-23	1.16	1.27	1.23
	Francis	15-18	1.16	1.26	1.23
	Skykomish	24-28	1.14	1.15	1.13
III	Stampede Creek[1/]	33-38	1.05	1.21	1.18
	Sayward	22-26	.93	.95	.94
IV	Rocky Brook	27-31	.66	.61	.67
	Shawnigan	25-31	1.02	1.08	1.06

[1/] Stampede Creek was more than 5.6 inches in d.b.h. at establishment, and projection for calibration period uses main stand routine.

At all installations except Stampede Creek, initial diameters were less than 5.6 inches. Therefore, projections were generated by the juvenile stand routine in DFSIM, beginning with values of number of trees and basal area after the calibration cut and using smoothed height trends, as before.

At Stampede Creek, where postcalibration diameter was more than 5.6 inches, projections are based on the main stand routine and are directly comparable with results for the treatment periods.

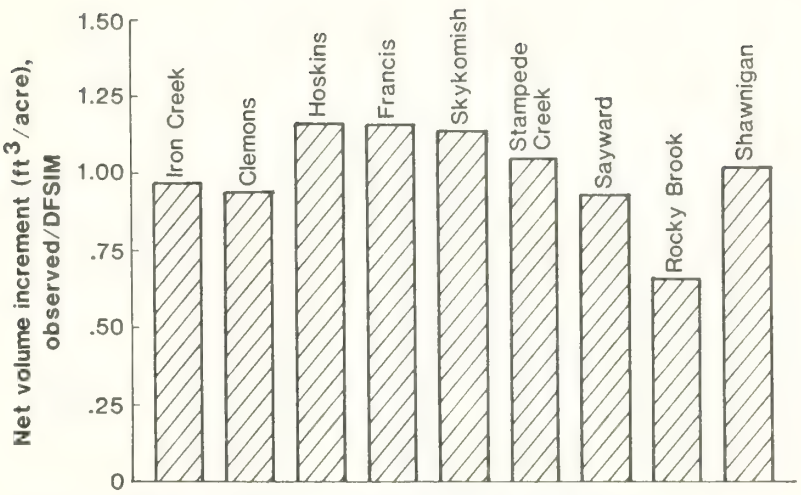

Figure 8—Ratios of actual net volume growth to DFSIM estimates, by installation; means of treatments 1, 3, 5, and 7 for calibration period only.

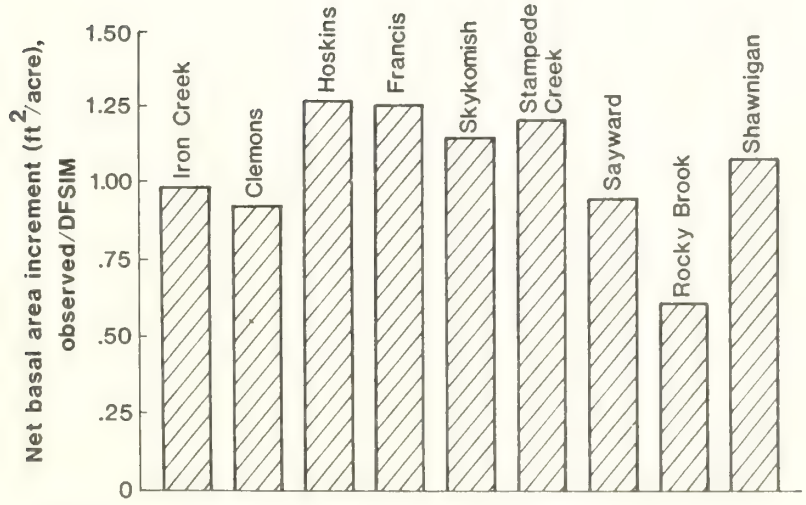

Figure 9—Ratios of actual net basal area growth to DFSIM estimates, by installation; means of treatments 1, 3, 5, and 7 for calibration period only.

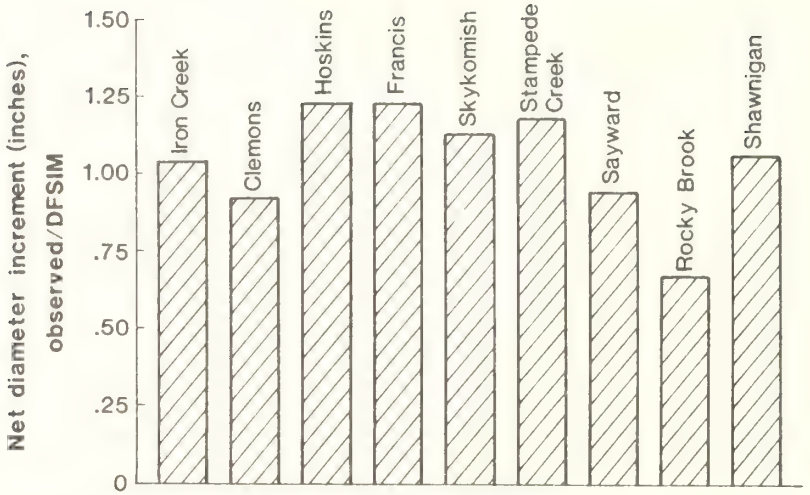

Figure 10—Ratios of actual net change in quadratic mean diameter to DFSIM estimates, by installation; means of treatments 1, 3, 5, and 7 for calibration period only.

Discussion

General notes.—Certain peculiarities of individual installations affect evaluation of results:

1. Skykomish, unlike other LOGS installations, is about 50 percent hemlock (*Tsuga heterophylla* (Raf.) Sarg.) by basal area. Average heights and diameters of the hemlock component are substantially less than those of the associated Douglas-fir component used as the basis for H40. Because species composition is quite different from that in the other LOGS installations and outside the stated range of applicability of DFSIM, little weight can be given to comparisons with this installation. Values are shown in tables and figures for people interested.

2. Iron Creek had substantial early mortality from bear damage (mostly during the calibration period) and, more recently, has had considerable mortality from root rot on several plots.

3. Rocky Brook suffered extensive snowbreakage shortly after establishment. More recently, extensive root rot has developed, scattered throughout the stand, and has caused one plot to be abandoned after the 1982 remeasurement.

Treatment period results.—

1. Gross volume increment: In the site II installations, averages across treatments of actual values and DFSIM estimates are comparable for Iron Creek, Clemons, and Francis; observed growth considerably exceeds predictions for Hoskins (and Skykomish). Figure 1 suggests that there is a consistent trend across treatments, with the higher growing-stock levels (treatments 5 and 7) having ratios of observed-to-predicted growth that are greater than 1.0, whereas lower growing-stock levels (treatments 1 and 3) in the same installations have ratios that are less than 1.0.

In the two site III installations, observed and predicted values appear in good agreement for the average of the two installations. Actual growth at Stampede Creek slightly exceeded predictions, whereas growth at Sayward was somewhat less than predicted.

Both site IV installations show substantially less gross volume growth than was predicted. Shawnigan is in better agreement with DFSIM than is Rocky Brook, possibly reflecting the known damage and disease problems at Rocky Brook. Again, the ratio of actual growth to predicted growth is highest at the highest growing stock level, treatment 7.

The differences across sites and across treatments are shown in an alternate form in figure 2, as regressions of ratios of observed/estimated gross volume increment on site index, fitted separately by treatment. (Skykomish is omitted because of its very different species composition and uncertain comparability.) Even with only eight installations, the regressions were significant at the 0.05 level for treatments 3, 5, and 7; the regression for treatment 1 was not significant.

Although the slopes of these lines differ significantly from zero, they do not necessarily represent an effect of site index only. Remember that (1) all treatments are begun from a common postcalibration low-density condition; (2) subsequently, treatments become increasingly different over successive periods as differing fractions of the gross growth on the controls are retained; and (3) stands progress through the sequence of treatment periods at rates that differ by site. Thus, the site II installations have now completed four to five treatment periods, whereas the site IV installations have completed one to two.

In the site IV installations, relative densities are not yet widely different and are still low. Therefore, the apparent relation of slopes to site index could in part reflect differences in average density associated with the different rates of stand development on different sites.

The order of elevations of the lines from treatments 1 through 7 indicates consistent differences associated with treatment (and stand density) for a given site index.

2. Gross basal area increment: The previous statements about gross volume increment also hold for gross basal area increment (table 2, fig. 3), although the range in values of the ratios of observed-to-predicted growth is greater, and the trend of increasing values with increasing growing stock appears more evident.

   Regressions of observed/estimated gross basal area increment on site index were also fitted, by treatment. Those for treatments 3, 5, and 7 were significant at the 0.10 level; the regression for treatment 1 was not significant. The relations were generally similar to those for the gross volume increment regressions discussed above, and the same interpretations apply.

3. Net change in diameter: Net change in stand average diameter shows a similar pattern (fig. 4). For the site II installations, the ratio of actual-to-predicted change exceeds 1.0 at Hoskins (and Skykomish) and is—on the average—about equal to 1.0 at Iron Creek, Clemons, and Francis. For the two site III installations,the ratio exceeds 1.0 at Stampede and is less than 1.0 at Sayward. Actual growth is less than predicted on both site IV installations.

4. Net change in number of trees: Net change in number of trees is compared in table 4 and figure 5. This is the combined result of removal of trees in thinning and loss of trees through mortality, primarily the former.

5. Mortality: Volume mortality and basal area mortality are compared in tables 1 and 2 and in figures 6 and 7. Observed mortality is highly erratic among treatments and among installations, and relative errors in predictions are large. Mortality losses in these thinned stands, however, have been minor (even though a few individual plots have been severely affected), and absolute errors are small. Mortality has had little effect on other stand statistics, and net growth in volume and in basal area (not shown) differs only slightly from gross growth.

Calibration period results.—Net volume, net basal area growth, and net change in stand average diameter appear to average close to DFSIM predictions (table 5 and figs. 8-10).

The most notable exception is Rocky Brook (site IV), for which growth during the calibration period was 30 to 35 percent below predictions. Rocky Brook, however, was severely damaged by snowbreakage at the start of the calibration period, and this could account for some of this discrepancy.

Growth for Hoskins and Francis (both site II) exceeded predictions by considerable margins.

Because DFSIM does not provide estimates of mortality for stands less than 5.6 inches in average diameter, basal area and volume mortality estimates are not available for the calibration period (except at Stampede Creek). Mortality has been minor at most installations, however, and gross growth relations would differ little from those for net growth, except possibly at Rocky Brook.

Comparisons for LOGS Controls

Analyses

Main stand routine.—Average diameters on control plots (treatment 9) are much less than those on thinned plots and do not reach 5.6 inches (at which point the main stand routine becomes operative) until considerably later than on the thinned plots. Three installations (Sayward, Rocky Brook, and Shawnigan) had not reached this point by the beginning of the most recent available growth period and are not included in these comparisons.

Age ranges represented by the data available from the remaining six installations are shown in tables 6 , 7 and 8, together with comparisons of actual growth with DFSIM estimates for gross growth, net growth, volume and basal area mortality, and net change in quadratic mean diameter and in number of trees.

Juvenile stand.—Comparisons of actual growth with predicted growth for the juvenile stand (D less than 5.6 inches) on the controls are seriously impaired because the available summaries do not separate ingrowth from survivor growth. Several installations have large numbers of ingrowth trees in an understory position on the controls, indicated by the sharp increase in recorded numbers of stems at the second and third measurements. Consequently, change in number of trees cannot be interpreted as mortality. And, because ending stand values include these ingrowth trees whereas initial values do not, change in diameter, volume, or basal area cannot be directly compared with DFSIM estimates generated from initial numbers and diameters.

Table 6--Comparison of observed values with DFSIM main stand routine projections of gross and net volume growth and mortality for controls only[1/]

Site, installation, and projection period ages (years)	Gross volume increment			Net volume increment			Volume of mortality		
	Observed	DFSIM	Observed/ DFSIM	Observed	DFSIM	Observed/ DFSIM	Observed	DFSIM	Observed/ DFSIM
	— ft^3 / acre —			— ft^3 / acre —			— ft^3 / acre —		
Site II:									
Iron Creek (30-37)	3,174	2,972	1.07	2,724	1,792	1.52	450	1,180	0.38
Clemons (26-40)	4,631	5,046	.92	4,031	4,325	.93	600	721	.83
Hoskins (27-40)	6,977	6,340	1.10	5,458	4,156	1.31	1,519	2,184	.70
Francis (25-37)	5,082	4,602	1.10	4,929	2,957	1.67	153	1,645	.09
Skykomish (28-46)	8,708	6,690	1.30	7,823	5,758	1.36	885	932	.95
Site III:									
Stampede Creek (43-48)	1,546	1,459	1.06	1,367	803	1.70	179	656	.27
Sayward[2/]									
Site IV:									
Rocky Brook[2/]									
Shawnigan[2/]									

[1/] Projections begin with actual basal area and number of trees at 1st measurement after attainment of average diameter of 5.6 inches or more.

[2/] Installation had not attained 5.6 inches in average diameter by the beginning of the last available growth period.

In this case, the largest number of trees recorded at any measurement (Nmax) was taken as an approximation of the actual initial number of trees, and DFSIM runs were made beginning with initial height and Nmax as initial number of trees. The program then generated a corresponding estimate of diameter. Stands were projected to the age at which the actual stand most nearly approximated 5.6 inches in diameter (or to the age at the last measurement, if this diameter was not attained).

Results are shown in table 8 as comparisons of actual and predicted volume, basal area, number of trees, and average diameter at the end of the projection period.

Discussion

Main stand routine.—It is evident that for the controls:

1. Observed gross growth and DFSIM estimates of gross growth in volume and in basal area are in reasonable agreement for all available installations except Skykomish (which is 50 percent hemlock and not directly comparable).

Table 7--Comparison of observed values with DFSIM main stand routine projections of gross and net basal area growth, basal area mortality, and net increment in quadratic mean diameter for controls only[1/]

Site, installation, and projection period ages (years)	Gross basal area increment			Net basal area increment			Basal area mortality			Net diameter increment		
	Obs	DFSIM	Obs/ DFSIM	Obs	DFSIM	Obs/ DFSIM	Obs	DFSIM	Obs/ DFSIM	Obs	DFSIM	Obs/ DFSIM
	ft^2/acre			ft^2/acre			ft^2/acre			inches		
Site II:												
Iron Creek (30-37)	56.3	54.2	1.04	38.8	13.3	2.92	17.5	40.9	0.43	1.08	1.61	0.67
Clemons (26-40)	94.3	96.9	.97	73.3	74.0	.99	21.0	22.9	.92	2.64	3.21	.82
Hoskins (27-40)	120.8	104.2	1.16	66.5	32.5	2.05	54.1	71.7	.75	3.36	3.16	1.06
Francis (25-37)	106.7	96.8	1.10	100.0	35.5	2.82	5.9	61.3	.10	1.64	3.10	.53
Skykomish (28-46)	162.0	114.8	1.41	153.0	87.1	1.76	29.0	27.7	1.05	4.44	4.45	1.00
Site III:												
Stampede Creek (43-48)	30.5	25.1	1.22	21.2	4.1	5.17	9.3	21.0	.44	1.23	.85	1.45
Sayward[2/]												
Site IV:												
Rocky Brook[2/]												
Shawnigan[2/]												

[1/] Projections begin with actual basal area and number of trees at 1st measurement after attainment of average diameter of 5.6 inches or more. Obs = observed value.

[2/] Installation had not attained 5.6 inches in average diameter by the beginning of the last available growth period.

2. Actual mortality has been much less than DFSIM estimates at all installations except Clemons and Skykomish, where the initial numbers of trees and attained densities were relatively low.

3. Actual net volume and basal area growth have been considerably greater than the DFSIM estimates because of the differences between actual and estimated mortality.

4. Ratios of net change in average diameter to DFSIM estimates are highly erratic and are frequently much less than the expected value of 1.0.

The relatively poor estimates of net change in diameter and net growth in volume and basal area on the controls can be attributed to two main factors: the presence of understory trees and the effect of the upper density limit in DFSIM.

The DFSIM main stand routine assumes that there is no ingrowth (that is, all trees are included in the stand statistics available when the stand reaches 5.6 inches in diameter) and that any understory trees of a younger age class have been excluded.

Table 8--Comparison of observed values with DFSIM predictions at end of the projection period for the juvenile stand for controls only: volume, basal area, number of trees, and quadratic mean diameter[1/]

Site, installation, and projection period ages (years)	Nmax	Est. initial D	Volume			Basal area			Number of trees			D		
			Obs	DFSIM	Obs/ DFSIM	Obs	DFSIM	Obs/ DFSIM	Obs	DFSIM	Obs/ DFSIM	Obs	DFSIM	Obs/ DFSIM
	no./acre	inches	ft^3/acre			ft^2/acre			no./acre			inches		
Site II:														
Iron Creek (19-30)	1,193	3.49	5,170	4,238	1.22	209.4	169.6	1.23	1,183	814	1.45	5.7	6.2	0.92
Clemons (19-26)	687	4.42	2,749	3,214	.86	124.7	137.8	.90	662	627	1.06	5.9	6.4	.93
Hoskins (20-27)	1,727	3.50	5,411	4,080	1.33	228.6	177.1	1.29	1,272	1,087	1.17	5.7	5.5	1.05
Francis (15-25)	1,127	2.77	4,060	2,957	1.37	190.1	141.2	1.35	1,107	926	1.20	5.6	5.3	1.06
Skykomish (24-28)	594	5.07	2,460	2,586	.95	108.7	120.4	.90	594	570	1.04	5.8	6.2	.93
Site III:														
Stampede Creek (33-38)	1,010	5.29	3,557	4,484	.79	152.0	175.2	.87	1,010	792	1.28	5.2	6.4	.82
Sayward (22-34)	1,100	3.74	4,481	3,887	1.15	182.7	163.1	1.12	997	841	1.19	5.8	6.0	.97
Site IV:														
Rocky Brook (27-44)	1,335	3.48	5,095	4,212	1.21	220.6	170.6	1.29	1,333	835	1.60	5.5	6.1	.90
Shawnigan (25-37)	1,192	3.75	3,581	3,236	1.11	160.9	149.9	1.07	1,138	930	1.22	5.1	5.4	.94

[1/] Nmax is the largest number of trees recorded at either the initial measurement or at any subsequent measurement. Estimated initial D is the diameter estimated by DFSIM from the given initial height and the largest number of trees recorded at either the initial or any subsequent measurement. Obs = observed value; D = quadratic mean diameter.

At several installations (Iron Creek, Francis, Rocky Brook) the controls contain a substantial "tail" of small stems of tolerant species. This has little effect on values of volume and basal area, but it has a major effect on values of average diameter and number of trees and on estimates that depend on these latter values.

For comparisons consistent with DFSIM estimates, these understory trees should be excluded. Unfortunately, the existing LOGS data summaries do not separate ingrowth or understory trees, which are present only on the controls. It was not feasible to resummarize the LOGS data to revised standards specifically for these comparisons. This factor introduces some uncertainty in interpretation of differences for the main stand routine and major uncertainties about the juvenile routine, discussed later.

The principal cause of DFSIM overestimation of mortality and net diameter growth for the LOGS controls is clearly the way in which DFSIM treats stands at the upper limit of density.

DFSIM does not allow stands to increase in density beyond about RD70 (Curtis and others 1981, Curtis 1982), a relative density value originally derived as an average of the older untreated stands in the DFSIM data base. As stands approach this limit, DFSIM accelerates mortality to prevent further increase in relative density.

Curtis and Marshall (1986) have shown that the controls on all the LOGS installations except Clemons and Skykomish exceeded RD70--sometimes by wide margins--over most of the range within which the DFSIM main stand projection routine is operative (fig. 11). The DFSIM estimates therefore include sharply accelerated mortality.

The principal results are (1) an overestimate of mortality and a corresponding underestimate of net growth in volume and basal area, and (2) a major overestimate of net diameter growth (analogous to the diameter increase that results from a low thinning) because of the change in average stand diameter associated with the removal of too many small trees as mortality. It is no accident that the estimates of net diameter change are in good agreement with observed values at Clemons and Skykomish, which did not reach the RD70 density limit until very late in the observation period.

Selected uniform stands, such as those represented in the LOGS installations, clearly can frequently exceed the RD70 limit. It is not known whether or not densities as high as those attained at Hoskins, Francis, and Iron Creek (RD90-RD100) can be maintained for an extended period, but they clearly are possible and even probable in unthinned plantations and very uniform natural stands.

Juvenile stand routine.—In general, DFSIM predicts a greater reduction in number of trees than has occurred (assuming that Nmax was close to the actual initial number). Differences in other values (volume, basal area, diameter) are associated with these differences in predicted numbers and probably arise from them.

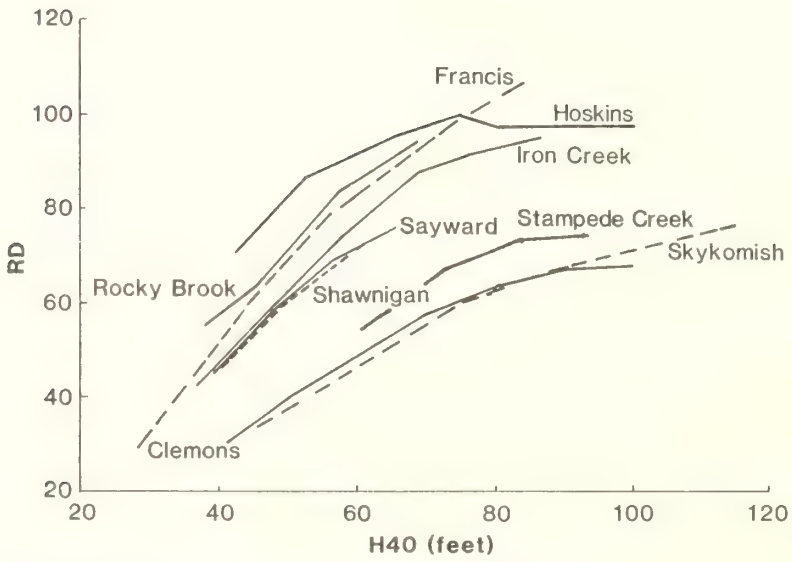

Figure 11—Trends of relative density (RD) over top height (H40) on LOGS controls, by installation.

Supplementary Comparisons

Supplementary comparisons were made with the Wind River spacing test (Reukema 1979) and the 0.5-acre plots from the University of British Columbia spacing test (Reukema and Smith 1987), with data made available by Donald L. Reukema and J.H.G. Smith. The first represents a long period of observation on a low site (site IV), whereas the second provides similar information, for a much shorter observation period on an excellent site (site I). Detailed results are not presented in this report, but they appear generally comparable to those from the LOGS data.

For the main stand routine, DFSIM somewhat overestimated gross volume growth, while seriously overestimating mortality at the closer spacings. The combined result is a serious overestimate of diameter growth at close spacings, but estimates of net volume growth that are fairly close to observed growth.

In the very limited comparisons possible, the juvenile stand estimates appeared consistent with the observed values.

Conclusions

The conclusions that can be drawn from these comparisons are necessarily limited because we have only eight locations, plus one (Skykomish) of doubtful comparability in species composition. Nonetheless, these comparisons do bring out several points of interest.

Thinned Plots

Overall, agreement with observation seems surprisingly good when we consider how different the LOGS thinned stands are from the majority of the data that went into DFSIM.

An apparent bias, associated with differences between treatments, probably represents the effect of differences in stand density. This is most clearly seen in the site II installations, where the ratios of observed growth to predicted growth are clearly higher in the higher density treatments.

There is also an apparent tendency toward overestimation on poor sites and underestimation on good sites; however, because differences in density of given treatments correspond to the different rates of development on different sites, this could be in part a concealed effect of density. With the site IV data limited to two installations--one of which now has only one treatment period available, and the other has two--no real conclusions can be drawn.

At the relatively low-stand densities found on the thinned plots, mortality is a minor factor in stand development, and the DFSIM estimates of mortality are in acceptable agreement with observation.

Controls

Somewhat surprisingly, estimates for controls have generally shown poorer agreement with observation than have those for thinned plots. This is due in part to the presence in some controls of substantial amounts of ingrowth and small understory stems of tolerant species, not specifically identified or separated in summaries. These trees, which should be excluded from comparisons, distort the number of trees and average diameter values and introduce uncertainties in comparisons.

A more clearly identifiable factor and a serious source of bias in DFSIM appears to be the fixed upper limit on relative stand density and the accelerated mortality used to prevent stands from exceeding this limit. This causes serious overestimates of diameter increment in dense stands and also affects net volume and basal area growth values.

The present limit of RD70 is a somewhat arbitrary average of values from the older untreated plots used as controls in various past thinning and fertilization studies. It is very close to the "normal" of McArdle and others (1961), which is widely accepted in the region for natural stands; however, mortality is probably greater and the limit on attainable stand density may be lower in natural stands than in uniform young stands, such as those that are included in LOGS and that are likely to be common in the future.

Clearly, vigorous, uniform young stands frequently develop relative densities well above RD70, in the absence of density control. The upper limit appears to vary among stands, for reasons unknown--a fact noted by others (Assmann 1970, King 1970).

Possible Changes in DFSIM

These comparisons, combined with others, suggest a need for modifications to the DFSIM stand simulation program.

First, the thinned plot comparisons suggest possible biases in the growth-stand density relations for thinned stands, and a possible but not clearly separable bias in relation to site. Modifications to correct this will have to await an updating of the data base with additional data for thinned and spaced stands, and a general reworking of the component relations. Such an update of the data and reworking of the simulator are highly desirable, both to correct perceived problems and to extend the range of applicability of DFSIM; but these do not appear immediately feasible because of current resource constraints.

A second, more clearly defined problem—and one that may be amenable to a "quick fix"—is the matter of the upper density limit. These and other comparisons have shown that young, uniform stands can frequently exceed the present limit of RD70 and that the current procedure of constraining stands to this limit by accelerating mortality can introduce substantial bias and can lead to unrealistic estimates for dense stands. The present density limit and the procedure used to constrain growth as stands approach the limit are both somewhat arbitrary. For vigorous uniform young stands, the default value for this limit should probably be higher than the RD70 used in the present version of DFSIM. A desirable refinement would be a provision allowing the user to alter the upper density limit to agree with local experience.

It may also be feasible to alter the density control routine so that gross growth is reduced concurrently with the acceleration of mortality as the density limit is approached. This would reduce or avoid the tendency to overestimate diameter growth of stands close to or beyond the density limit.

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Initial stand statistics for the levels-of-growing stock-study installations were projected by the Douglas-fir stand simulation program (DFSIM) over the available periods of observation. Estimates were compared with observed volume and basal area growth, diameter change, and mortality. Overall agreement was reasonably good, although results indicate some biases and a need for revision of the upper density limit in the DFSIM program.

KEYWORDS: Simulation, projections (stand), model validation, statistics (stand), growing stock (-increment/yield, Douglas-fir, *Pseudotsuga menziesii.*

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Values and Choices in Outdoor Recreation by Male and Female Campers in Dispersed Recreation Areas

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Abstract

Christensen, Harriet H.; Williams, Paula J.; Clark, Roger N. Values and choices in outdoor recreation by male and female campers in dispersed recreation areas. Res. Pap. PNW-RP-377. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1987.** 20 p.

Objective information is generally lacking about women and their satisfactions and experiences from participation in outdoor recreation. Data were gathered from campers in three National Forests in Washington and Oregon. Attitudes, preferences, perceptions, and reported activities of men and women campers were compared. Overall, responses showed more similarities than differences; men and women were similar in their usage patterns, activity preferences, perceptions of problems, and attitudes about management practices. Small differences were present, however, and managers need to be aware of these differences when integrating recreation with other forest activities.

Keywords: Dispersed recreation, recreation surveys, recreation management, human behavior.

Summary

Men and women using dispersed, roaded recreational areas in the Pacific Northwest were surveyed to determine the similarities and differences (1) in patterns of use, (2) in preferences for settings and for various outdoor activities, (3) in perceptions of management problems, and (4) in attitudes about management activities.

Overall, men had a longer history of use in these dispersed areas; men had visited the areas for 8 years before the interview as compared to women, who had visited for 6 years.

Childhood experiences with camping were different for men and women; more men than women had participated in dispersed recreation areas as children. Women either did not camp as children or, if they did, they camped in dispersed or minimally developed areas. Women expected to increase their visits to dispersed roaded areas in the next few years; men did not perceive a change in their use.

Of the 40 possible activities listed in the survey, 17 were similar for men and women and 23 activities were different. Both men and women preferred certain motorized activities, such as riding in four-wheel drive vehicles and on motorbikes. Women were more likely than men to like day hiking, swimming, nature walks, bicycling, picnicking, playing in the snow, picking berries, and collecting rocks. Men were more likely than women to like snowmobiling, fishing, hunting, target shooting, overnight backpacking, snowshoeing, and cutting firewood for home use.

Overall, men and women were more similar than different in their perceptions of management problems. More women than men felt that the Forest Service should alert users to potential hazards, such as poisonous snakes, dangerous roads, and polluted water. More men than women saw vandalism and theft of equipment as more of a problem and saw noise from motorbikes and lack of maps as becoming problems.

Some similarities between men and women were shown in their attitudes about management activities, such as the impact of large-scale logging on the landscape, closing roads, and rules and regulations in the areas. Men and women were similar in feeling that clearcutting was "okay" but were different in that more men than women felt that way. Closing roads to improve hunting quality was more likely to be supported by men than by women.

Much has been written on the similarities and differences between women and men in the social world, but there is little literature comparing experiences for men and women in outdoor recreation. In this study, more similarities than differences were found between men and women. The differences may be attributable to different levels of experience in the outdoors or may be influenced by other gender-linked values.

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Introduction

Research about outdoor recreation has historically focused more on men and their attitudes and behavior than on women. The studies have generally emphasized activities such as hunting, fishing, and mountain climbing (Kelly 1980, Unkel 1981). Manufacturers of outdoor equipment, organizers of recreational trips, and authors of popular literature have recently begun to recognize women's participation in outdoor recreation, and more and more suppliers are changing and updating inventories and services to meet women's needs.

Both men and women are committed to outdoor experiences, but much less is known about what women do, the meaning of the experience to women, and the role that women play in choosing the type of recreation (Stankey and McCool 1985). It is important to understand the nature, extent, and meaning of women's participation in outdoor recreation to assess the influence those experiences have on overall participation and on the demand for recreational resources.[1/] The meaning of women's experiences has not received much attention in the literature, but it may have important implications for managers as well as users.

In this paper, we summarize the literature on outdoor experiences and compare similarities and differences between male and female campers in a motorized, dispersed recreation area. Behavior, attitudes, perceptions, and preferences are discussed.

Theoretical Perspective

In comparing similarities and differences between men and women, we are using the term "gender" as suggested by Lopata and Thorne (1978), Tresemer (1975), and other sociologists. Gender refers to social and cultural distinctions between men and women that are learned—it does not refer to either biological (sex) distinctions or to sexuality, sexual preference, or sexual identification. As Lopata and Throen (1978:719-721) note:

> Gender, like race or age, is deeper, less changeable, and infuses the more specific roles one plays . . . Gender identification pushes, pulls, encourages, or discourages entrance into functionally organized roles . . .
>
> The point that I am making here is that I cannot locate a sex role, or even a gender role, seeing only the influence, more or less pervasive, of gender identification and self-identity upon the social roles selected and entered into by men and women and upon the relations with members of the social circles of these roles. It seems to be that being a woman is not a social role but a pervasive identity and a set of self-feelings which lead to the selection or the assignment by others of social roles and to the performance by women of common roles in some ways differently from men.

1/ Cheek, N.H., Jr. "Recreational activities: a preliminary investigation of structural properties." Paper presented at the Texas Academy of Science, Annual Meeting; 1978.

Integrating gender into social theory, and the sociology of leisure and recreation in particular, is relatively recent (American Sociological Association 1980). Studies appearing in "Leisure Sciences" and the "Journal of Leisure Research" have generally taken one of these approaches: both men and women were included but there were no data analyses on differences by sex (Cheek 1976, Vernon 1976); findings were reported separately for women and for men, thereby implying that sex may be an important variable (Driver and Knopf 1977, Iso-Ahola 1979, Kleiber 1980); and specific patterns for men vs. women were compared (Unkel 1981).

Most studies examining the patterns in leisure and recreation for men and for women focus on actual behavior and suggest that the types of activities and rates of participation are different.

Amounts and Types of Outdoor Activities

Participation in recreational activities has commonly been measured by occurrence or by whether or not a person engages in a particular activity. Studies have found that men engage in a wider range of activities than do women; for instance, studies of hunting (Starnes 1980, Uzendoski 1967), fishing (Bryan, 1979), riding dirt bikes (Watson and others 1980), mountain climbing and surfing (DeVall 1976), and collecting and displaying antique cars (Dannefer 1980) are studies of primarily male-oriented recreation. Men tend to report participation in outdoor activities and team and spectator sports, whereas women report participation in cultural activities. Some activities, such as individual or dual sports, may have similar rates of participation by men and women[2/], (Theobald 1978, Unkel 1981, Zuzanek 1978).

Some studies have focused on the relationship between participation in activities and personality attributes (Gentry and Doehring 1979, Iso-Ahola 1979, Kleiber 1980, Maloney and Petrie 1972). These studies suggest that men and women derive different satisfactions (Ragheb 1980) and outcomes (Driver and Knopf 1977) from their recreational participation. These studies also suggest that gender influences not only the extent and intensity of participation but related attitudes and perceptions as well (see footnote 1).

Research suggests that differences in recreational preferences of men and women increase with marriage and the family and decrease after children enter school (Angrist 1967, Bernard 1981, Burch and Wenger 1967, Kelly 1980, Rapoport and others 1975, Unkel 1981, Witt and Goodale 1981). Other studies focus on patterns, by sex, in recreation for specific age groups—such as adults (Unkel 1981), college students (Kleiber 1980), or adolescents (Crompton 1978).

2/ Crompton, J.L. "The participation of male and female adolescents in selected outdoor recreation activities." Manuscript written for Heritage Conservation and Recreation Service, U.S. Department of the Interior; 1978.

Participation in recreational activities also varies with the social group one recreates with (Samdahl 1979); for example, women are more likely to fish with their families, whereas men may fish alone or with family and friends (Dottavio and others 1980, Field and others 1975). Participation patterns are also linked to lifestyle, values, and social class; for instance, working-class individuals are more likely to engage in leisure activities differentiated by sex than are middle-class individuals who are more likely to participate in activities without regard to sex (Bott 1971, Rapoport and others 1975, Rubin 1976).

The amount of leisure time available to an individual is affected by the time spent at work and with family and community obligations. Studies show that women have less leisure time than men, particularly if employed outside the home (Cheek and Burch 1976, Govaerts 1969, Lee 1979, Zuzanek 1978). Other factors affecting participation by women include lack of child care, lack of basic skills and knowledge to participate in a given activity, fears regarding personal safety, and other cultural factors (Boothby and others 1981, Farmer 1976, LaBastille 1980, Theobald 1978, Thomas 1980).

Overall, the literature shows that various factors, such as stage in the family life cycle, membership in a social group, and amount of leisure time, influence participation in activities outdoor in different ways for men and for women.

Meanings of Outdoor Activities

Participation by men and women in outdoor activities is well documented; however, little is known about the experiential component, particularly for those people engaging in the same activity. Women have been described as onlookers, invited guests (with male escorts or sponsors), consumers, or low-level functionaries who carry out the daily work of the setting (Peterson and others 1978). Women may go on fishing trips as companions or perform other functions like watching children or preparing meals, but they rarely go with fishing as a primary motive[3/] (Burch 1965). Studies of organized recreational trips have found that few leaders are women (Galland 1980, Thomas 1980).

Researchers have also inquired about the characteristics of the female world (Bernard 1981); the assumption is that females and males experience the world differently and attach different meanings to their activities (Gilligan 1982, Smith 1979). We know, for instance, that throughout the ages females have had a different relation to nature than have men; this is particularly true in Western industrial cultures (Galland 1980, Griffin 1978, LaBastille 1980, Merchant 1980).

In summary, the available literature suggests that men and women tend to differ in the frequency and type of activity in which they participate. Furthermore, participation and satisfaction in outdoor recreational activities are not fully understood, although some evidence suggests that meanings associated with particular activities are different for men vs. women.

3/ Field, D.R.; Burdge, R.J.; Burch, J.S. "Sex roles and group influences on sport fishing behavior." Paper presented to Rural Sociological Society Annual Meeting (21-24 August, San Francisco); 1975.

Objectives

The purpose of the study was to compare the attitudes, perceptions, preferences, and reported activities between male and female campers. Specific objectives were to identify the similarities and differences (1) in patterns of use of dispersed recreation, (2) in preferences for various outdoor activities, (3) in perceptions of management problems such as vandalism, and (4) in attitudes about management activities such as logging and road management practices.

Methods

In response to information needs of managers, the Wildland Recreation Research Work Unit of the Pacific Northwest Research Station began studying settings for dispersed, roaded recreation during 1975. These settings were generally undeveloped with few or no conveniences and were characterized by campsites established by users and by dispersed patterns of use (Buist and Hoots 1982, Clark and Stankey 1979). The dispersed areas selected for study were in the Mount Baker-Snoqualmie and Wenatchee National Forests, Washington, and the Mount Hood National Forest, Oregon.

A series of related studies were conducted in the three forests. During the first phase of the study, campsites were inventoried, and the nature and extent of use were determined (Hendee and others 1976a, 1976b). In the second phase, a user survey was done to determine patterns of dispersed day use and overnight use and patterns of activities associated with settings, recreational preferences, perceptions of management problems, and attitudes about forest management activities (Clark and others 1984). Information from overnight users form the basis for this paper.

Brief interviews were conducted with campers between July and November 1976. Information collected included composition of the group, camping facilities and equipment the campers brought with them, number and type of domestic animals present, and purpose of the camping trip. The second part of the survey was a nine-page questionnaire with 88 questions about the preferences, experiences, and patterns of use; perceptions of management problems; and attitudes the campers had about selected management activities.

Questionnaires were distributed to campers at their campsites. Brief interviews were conducted and questionnaires were distributed to one man and one woman in the camping group. We included women in the study to compensate for the general exclusion of women in previous studies on outdoor recreation. Questionnaires were to be returned to USDA Forest Service personnel at the site or to be mailed to an office. To follow up, we mailed two postcards and a second questionnaire at 1-week intervals to the campers at their home addresses. Overall, out of 1,321 questionnaires that were distributed to overnight campers in the three areas, 898 were returned for a response rate of 68 percent. For a detailed discussion about procedures, see Clark and others 1984.

The results we report here are subject to certain limiting factors. We don't know if the field assistants influenced the responses of the campers; both assistants were male, so it is possible some responses were affected by this suggestion that camping is a male activity. We were also unable to determine the actual independence of responses by men and women. The questionnaires were completed after the interviewer left the campsite or when the campers returned home, so we don't know who completed the survey and under what conditions. To the extent that these limitations occurred, the extent of the differences in responses by gender may have been depressed; that is, if party members discussed their responses, differences would not be expected in those responses. And, nearly 10 years have passed since the study was completed. The extent to which changes have occurred in our society in general, and in recreation in particular, that would affect our results is unknown. Replications of the original study are planned to document the nature and extent of such changes. But this study does represent one of few attempts to address differences and similarities of women and of men and potential implications for resource managers and future research.

Results and Discussion

This paper is based on the responses obtained from campers who stayed one or more nights in three dispersed, roaded recreational areas. Some background about the respondents is summarized:

- Forty-five percent of the 898 overnight campers were women and 55 percent were men.
- Men averaged 40 years of age and women 36 years.
- Thirty-eight percent of the men completed college as compared to 32 percent of the women.
- More than half of the women (53 percent) and most of the men (88 percent) were employed.
- Users generally camped in pickup campers, trailers, and tents for about 4 nights.
- The average size of the camping party was six people.

Results are summarized below in four sections: patterns of use, preferences for settings and activities, perceptions of management problems, and attitudes about management activities. At the beginning of each section, we briefly describe similarities in the responses from men and women; this is followed by a discussion of the differences.[4/]

4/ Two statistical tests of significance were used to reveal differences between the two groups: (1) t-statistics (and probability) to determine differences between means and (2) chi-square. A significant difference was defined as one that occurred at least no more than 5 percent of the time or at the 0.05-level of significance. The magnitude of the relations between variables was measured by gamma—gamma ranged from -1.0 to +1.0. Gamma allows one to determine the proportion of variance explained in the dependent variable by knowledge of the independent variable; for example, a gamma value of 0.26 indicates that 26 percent of the variance in the dependent variable can be explained by knowledge of the independent variable. The closer gamma comes to zero, the weaker the relation becomes (Blalock 1972, Mueller and others 1977).

Patterns of Dispersed Recreation Use

Patterns of use of dispersed recreation (table 1) are compared for men and women. Similarities between men and women included:

- They visited dispersed recreational areas five times during the previous year and made fewer visits to minimally and highly developed campgrounds.
- Length of stay was 4 nights.
- The usual size of the group was six individuals.
- Campers learned about the area through family, friends, or acquaintances.

Differences between men and women included:

- Men had a longer history of use in these dispersed areas; men reported having visited the area for 8 years before the interview as compared to women who had visited for 6 years.

Preferences for Recreation Settings

Preferences for recreational settings (table 2) are compared for men and women, specifically, their history as children camping in different settings, their camping preferences today, and their projected future plans for camping in dispersed roaded settings.

Similarities included:

- Men and women were similar in their preferences for forest recreational areas; their first choice was dispersed, roaded areas followed by minimally developed campgrounds and roadless or wilderness areas.

Differences included:

- Experiences with camping as children were different for men and women; more men (37 percent) than women (23 percent) participated in dispersed recreational activities as children.
- Men, as children, visited dispersed recreation areas more frequently than they did roadless areas, wilderness areas, or highly developed areas.
- Women either did not camp as children, or they camped in dispersed or minimally developed areas.
- Women expected to increase their visits to this dispersed, roaded area in the next few years; men did not perceive a change in their use of the area.

Table 1—Reported patterns of use by campers

Patterns of use 1/	Campers 2/ Female	Male
Number of trips made by campers to each area last year, in mean years:	(N=369)	(N=445)
Highly developed campgrounds (t=1.72, p=0.9, N.S.)	1.2	1.5
Minimally developed campgrounds (t=1.16, p=0.11, N.S.)	2.8	3.2
Dispersed roaded recreation area (t=2.14, p=0.04 *)	5.0	5.0
Roadless or wilderness areas (t=1.71, p=0.09, N.S.)	1.2	1.5
Length of stay:	(N=394)	(N=482)
Number of nights party stayed at site, mean (t=1.71, p=0.09)	3.7	4.4
Size of party:	(N=394)	(N=482)
Number of people in camping party, mean	6.1	5.5
Number of years camper has been visiting this dispersed roaded recreation area, in mean years (t=4.86, p=0*)	(N=394) 5.6	(N=482) 8.3
How campers first learned about this area, in percent:	(N=386)	(N=473)
Friends or acquaintances (t=0.14, p=0.89, N.S.)	47	47
Family (t=2.75, p=0.01 *)	25	17
Land management agency representative or official (t=1.28, p=0.20, N.S.)	--	1
Newspaper, magazine, or mass media (t=0.42, p=0.68, N.S.)	1	1
Organization or club (t=0.03, p=0.98, N.S.)	1	1
Publication, map, or brochure (t=0.93, p=0.35, N.S.)	2	3

1/ The information in parentheses is the t-statistics and probability, and the asterisk (*) represents significance at the specified level.

2/ N is the number of respondents.

Table 2—Preferences for recreation setting

Users' preferences	Campers 1/ Female	Male
Types of recreational camping participated in as a child, in percent: 2/	(N=383)	(N=475)
Highly developed campgrounds (t=-1.22, p=0.22, N.S.)	12	9
Minimally developed campgrounds (t=0.02, p=0.98, N.S.)	27	27
Dispersed roaded recreation area (t=4.59, p=0*)	23	37
Roadless or wilderness areas (t=5.30, p=0*)	11	25
Other (t=-1.45, p=0.15, N.S.)	4	3
Did not camp as a child (t=-3.98, p=0*)	35	23
Campers preference for different forest recreational areas, ranked by means:	(N=358)	(N=441)
Highly developed campgrounds (t=1.09, N.S.)	3.4	3.5
Minimally developed campgrounds (t=1.82, p=0.07, N.S.)	2.0	2.1
Dispersed roaded recreation area (t=-0.80, N.S.)	1.5	1.5
Roadless or wilderness areas (t=-1.80, p=0.07, N.S.)	3.1	2.9
Perceived change in use during the next few years, in percent: 3/		
Dispersed roaded recreation areas--		
Increase	66.6	59.6
Remain the same	29.3	37.1
Decrease	4.1	3.3
(X^2, 2 df = 5.60 p=0.06)		

1/ N is the number of respondents.

2/ The information in parentheses is the t-statistics and probability, and the asterisk (*) represents significance at the specified level.

3/ The information in parentheses is the chi-square and probability, and the asterisk (*) represents significance at the specified level.

Overall, women had used dispersed areas less than men as children and with fewer trips each year. Many women had not camped as children and were far more likely to learn about dispersed camping areas through family members than were men. In comparison, men were much more likely than women to learn about the areas through exploration. These findings suggested different patterns of socialization into dispersed recreational areas for women and men. Women's adult recreational patterns, as Iso-Ahola's (1980) research suggests, may be more dependent upon situational factors than are men's. Women's recreational patterns, at least in this setting (dispersed roaded area), may be more dependent on the patterns and preferences of the men with whom they recreate. One might suggest, alternatively, that outdoor recreational activity is becoming a more acceptable sphere of activity for women, and these changes in participation reflect women's overall increasing participation in numerous aspects of social life. The women in our study were more likely than the men to expect changes in future use levels—either increasing or decreasing—both in dispersed and roadless areas.

Preferences for Recreational Activities

Most studies of leisure and recreation suggest that types of activities and rates of participation are different for men and women. In this study, campers were provided with a list of activities that might take place in their dispersed, roaded recreation area. We asked them to "check the ones that you like to engage in when you visit this area." The list consisted of motorized activities, outdoor activities, campsite activities, or gathering forest products. The items chosen for the questionnaire were based on the standard SCORP (State Comprehensive Outdoor Recreation Plan) categories; activities not suitable for dispersed areas were eliminated (for instance, golf), and other activities were added (for example, gathering forest products). Campers could write in other activities of interest. Of the 40 activities, 17 were similar for men and women, and 23 activities were different (table 3).

Similarities included:

- Both men and women preferred certain motorized activities, such as riding in four-wheel drive vehicles and riding motorbikes.
- Around the campsite, both men and women enjoyed doing camp chores and viewing natural scenery.
- Outdoor activities preferred by both men and women included photography and boating or canoeing.

Differences included:

- Females were more likely than males to like day hiking, swimming, nature walks, bicycling, picnicking, playing in snow, picking berries, collecting forest specimens, and collecting rocks.
- Women preferred short walks near camp, visiting with companions in the same group, singing or enjoying music, resting or relaxing, playing outdoor games, drawing or painting, sunbathing, reading, and playing cards.
- Males were more likely than females to like snowmobiling, fishing, hunting, target shooting, overnight backpacking, snowshoeing, and cutting firewood for home use.

Table 3—Reported preferences for activities by male and female campers

Activity	Campers		T-value	Ranking	
	Female	Male		Female	Male
	- -Percent- -				
Campsite activities:					
Resting, relaxing	86	76	-3.93***	1	3
Short walks near camp	85	72	-4.82***	2	4
Doing camp chores (gathering wood, building fires, cooking)	83	80	-1.35	3	2
Visiting with companions in same group	77	68	-2.85**	4	6
Viewing natural scenery	76	71	-1.57	5	5
Reading	58	29	- .04***	8	20
Playing cards	51	40	-3.20***	9	10
Sunbathing	48	26	-6.92***	11	21
Playing outdoor games (frisbee, horseshoes, catch)	42	38	-1.04	15	12
Singing or enjoying music	34	24	-3.45***	20	25.5
Drinking alcoholic beverages	29	34	1.32	23	16
Visiting with people from other groups	25	24	- .42	25	25.5
Drawing, painting	11	3	-4.32***	36	40
Outdoor activities:					
Fishing	75	82	2.44*	6	1
Nature walks to observe plants, birds, and animals in their natural surroundings	62	47	-4.47***	7	8
Day hiking to adjacent areas	46	35	-3.15**	12	14
Picnicking	45	30	-4.58***	13	17
Hunting	43	64	6.64***	14	7
Swimming	38	26	-3.98***	19	22.5
Photography	33	29	-1.11	21	19
Playing in the snow	22	14	-2.95**	26	32
Boating or canoeing	19	20	.57	27	27
Target shooting or plinking	18	36	5.95**	26	32
Mountain climbing	16	16	.12	31	31
Horseback riding	15	14	- .54	32	33
Rafting and river floating	14	11	-1.52	33	35.5
Bicycling	14	6	-3.86***	34	37
Backpacking to adjacent areas (overnight)	10	17	3.28***	37	29
Cross-country skiing	2	4	1.63	39.5	38.5
Snowshoeing	2	4	2.54*	39.5	38.5
Motorized activities:					
Driving and sightseeing from vehicle	50	44	-1.83	10	9
Motorbike riding	39	39	.19	18	11
Four-wheel driving or jeeping	25	30	1.56	24	18
Snowmobiling	7	2	2.46*	38	34
Gathering forest products:					
Berry picking	41	35	-1.84	16	15
Collecting specimens, such as flowers, insects, drift-wood, or cones	40	17	-7.68***	17	30
Collecting rocks	32	24	-2.52*	22	24
Cutting firewood for home use	17	26	3.00**	29	22.5
Gathering natural foods such as mushrooms and edible plants	16	19	.99	30	28
Christmas tree cutting	11	11	- .06	35	35
No activities mentioned	.8	1.5			
Total number of respondents	(394)	(482)			

Level of significance: *0.05, **0.01, ***0.001.

A distinction needs to be made between the preference for an activity and the experience or meaning of participating in an activity. Activities listed in table 3 are not exclusive—many may be engaged in simultaneously; for example, a camper may rest and relax while visiting with companions of their own or another group and enjoy music or sing. The activities are not independent of each other. Several activities may, in fact, be important to users, and the experience may encompass multiple satisfactions (Hendee and others 1977).

It is misleading to infer the same meaning for both men and women from one activity. For men, fishing, relaxing, and visiting with companions may be related, but for women fishing may be neither relaxing nor social (Samdahl 1979). These data do not address whether the experiences behind these activities are the same or different. Further studies are necessary to sort out such relations.

Perceptions of Management Problems

Campers were asked to arrange a list of potential management problems by perceived importance (tables 4 and 5). Overall, we found more similarities than differences between men and women. The differences we found were statistically significant but were small.

Similarities included:

- Men and women generally felt safe from forest fires and logging traffic.
- Both men and women perceived litter and garbage as becoming a problem.
- Main streams in the area were clear enough to drink.
- Dust from roads was seen as a problem.
- Lack of directional signs on roads was "okay."

Differences included:

- More women than men felt that the Forest Service should alert users to potential hazards, such as poisonous snakes, dangerous roads, and polluted water.
- More men than women saw theft of equipment as becoming a problem.
- More men than women thought noise from motorbikes was a problem or was becoming one.
- Men saw vandalism as more of a problem.
- More men than women perceived the lack of maps as becoming a problem.

Table 4—Perceptions reported by campers about management problems

Management problems	Attitude			Total response 1/
	Agree	Neutral	Disagree	
	- - - - - - - Percent - - - - - - -			
Safety				
The Forest Service should alert users to potential hazards in dispersed road recreation areas (such as poisonous snakes, dangerous roads, polluted water, etc.):				
Female	91	3	6	100 (N=392)
Male	85	8	7	100 (N=477)
Sanitation				
Human body waste disposal is really not an important problem in dispersed areas because nature quickly takes care of it:				
Female	38	16	46	100 (N=386)
Male	46	14	40	100 (N=471)

1/ N is the total number of respondents.

Men and women expressed similar perceptions of management problems. Differences found were small and subtle. One of the more apparent differences between men and women was over the lack of maps. Possible explanations for this are that men were more aware than women of the advantages of having a map in their possession as a result of more experience in dispersed, roaded areas; that rapid changes were occurring through logging activities in some locations, and men felt a greater need for maps as a result; and that exploring and viewing scenery were favorite activities of men and maps enhance this activity.

Table 5—Perceptions reported by campers about management activities

Management activities	Attitude				
	Now a problem	Becoming a problem	Not now a problem	No opinion	Total response1/
	- - - - - - - - - - Percent - - - - - - - - - -				
Depreciative behavior					
How important do you feel the following are in this area?:					
Vandalism--to personal or private property--					
Female	6	37	47	9	100 (N=388)
Male	9	36	47	8	100 (N=479)
(X^2=15.60, p=0.001, Υ=0.21[2])					
Theft of equipment					
Female	4	25	62	9	100 (N=386)
Male	5	33	53	9	100 (N=480)
(X^2=8.55, p=0.03, Υ=0.15*)					
Other impacts					
Noise from motorbikes:					
Female	10	35	50	5	100 (N=388)
Male	17	38	41	4	100 (N=460)
(X^2=10.9, p=0.01, Υ=0.18*)					
User information					
Lack of maps:					
Female	7	27	50	16	100 (N=385)
Male	9	35	45	11	100 (N=474)
(X^2=10.97, p=0.01, Υ=0.18)					

1/ N is the number of respondents.

2/ The information in parentheses is the chi-square and probability, and the asterisk (*) represents significance at the specified level.

Attitudes About Selected Management Activities

Campers were asked to respond to several statements about management activities, such as road management, logging, rules and regulations, and agency presence (table 6).

Similarities between men and women included:

- The impact of large-scale logging on the landscape would detract from enjoyment of the area.
- It was "okay" to close some roads for road maintenance or repair, to protect wildlife, and to reduce fire hazards.
- The current rules and regulations in the area were reasonable.

Table 6—Attitudes of campers about selected management activities for roads

Activity and respondents 1/	Attitude			Total response 2/
	Agree	Neutral	Disagree	
	- - - - - - - Percent - - - - - - -			
It's okay to close some roads to vehicles to improve hunting quality:				
Female	49	21	30	100 (N=378)
Male	63	11	26	100 (N=474)
(X^2=19.95, p=0, Y=-0.20*)				
Paving of a few main forest roads for dispersed recreation would be a good policy:				
Female	34	19	47	100 (N=392)
Male	29	12	59	100 (N=479)
(X^2=14.59, p=0.001, Y=0.18*				
More roads should be constructed in this area:				
Female	14	30	56	100 (N=383)
Male	10	18	72	100 (N=474)
(X^2=23.33, p=0, Y=0.29*				

1/ The information in parentheses is the chi-square value and the measure of association, and the asterisk (*) represents significance at the 0.05 level.

2/ N is the number of respondents.

Differences included:

- Clearcuttings were "okay" but more so to men than to women.
- Closing roads to improve hunting quality was more likely to be supported by men than by women.
- Building more roads in the areas was favored more by women than men.

Men and women had various attitudes about management activities. Campers' views regarding the appropriateness of rules and regulations in the area were requested. Freedom and general lack of regimentation were features users of dispersed, roaded recreational areas preferred. In fact, many dogs ran free, target shooting was allowed, and people in general were unencumbered by rules and regulations.

Men and women were split in their response to the statement, "It's okay to close some roads to vehicles to improve hunting quality." The majority of men (63 percent) agreed with the statement, whereas about one-half (49 percent) of the women agreed. We would expect men to favor a management practice to improve hunting quality because hunting was a preferred male activity.

Both men and women viewed paving a few main forest roads for dispersed recreation and construction of more roads as inappropriate. More men than women were against road construction in both cases. One of the largest differences in the study was over the statement about constructing more roads; 72 percent of the men disagreed with this statement vs. 56 percent of the women.

A pattern that appeared throughout the study was women giving a higher percentage of "neutral" or "no opinion" responses than men did. In the example above, for instance, more women than men were neutral on the item that roads should be constructed, 30 percent versus 18 percent. The one exception to this pattern was the strong opinion women had about the Forest Service responsibility to alert users to potential hazards (for example, poisonous snakes, dangerous roads, and polluted water). This higher "neutral" response perhaps indicated a general lack of knowledge about the area, or it may have been a reflection of socialization factors for women, such as lack of assertiveness, resistance to change, and an unwillingness to trust their own judgment (Franks and Rothblum 1983).

Conclusion

This paper focused on the similarities and differences in attitudes and behavior between men and women camping in three dispersed, roaded areas in Oregon and Washington. Much has been written on the differences between women and men in the social world, but there is very little about the differences in experiences for outdoor recreation. This analysis of campers in a dispersed setting was an effort to answer the question, How are men and women similar and dissimilar in patterns of use, activity preferences, in perceptions of management problems, and in attitudes about management activities? What was striking about the results was the amount of similarity between men and women. Although some differences were noted, they were generally small. The validation and elaboration of our findings require further study. Why men and women perceived or felt differently about an issue may be attributed to different experience levels in the outdoors, or it may be influenced by other gender-linked values. The men in our sample had more experience in the outdoors as children than the women did and had been visiting the particular dispersed area for a longer period of time.

In considering differences between men and women in outdoor recreation, researchers need to consider both the population being sampled and the actual behaviors being studied. Thus, it is misleading to report that males engage in a wider range of outdoor recreational activities than do females (Zuzanek 1978). The range of activities is a reflection of the sample, the given list of activities, and the respective salience of those activities to females and males. In this study, females, on the average, liked to engage in more activities than did males. This finding holds only for this sample and for this list of activities. Several of the activity choices—such as those under "gathering forest products" or "campsite activities"—are not part of conventional studies, yet they contain many activities preferred by females. Thus, much previous research found that males engage in more activities because the research focused on male activities. Similar findings have emerged in other areas of social science research (Sherif 1979). This suggests that to understand female involvement in outdoor activities we need to broaden our perspective to look at all possible activities for men and women and not just at traditionally defined activities.

Research needs are many, and most important is the need for longitudinal studies on the experiential differences between men and women: Are experiences and meanings of activities different or alike for men and women? How are values changing? Do differences occur as a result of opportunity and experience, or can they be accounted for by socialization factors such as values? Does the concept of a party leader still hold with mixed-sex groups or is group consensus the practice among these campers? How might differences influence the choice of a particular form of recreation (Stankey and McCool 1985)? Such research needs to differentiate attitudes among all-male groups, all-female groups, and mixed groups.

Certainly the increase in female participation in outdoor recreation and the limited information about similarities and differences between men and women suggest the need for further study. The focus needs to be on the motives, meanings, and experiences behind the activities men and women select. Such information will enhance management to manage for particular types of users and for recreational opportunities in roaded forests.

Acknowledgments

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Objective information is generally lacking about women and their satisfactions and experiences from participation in outdoor recreation. Data were gathered from campers in three National Forests in Washington and Oregon. Attitudes, preferences, perceptions, and reported activities of men and women campers were compared. Overall, responses showed more similarities than differences; men and women were similar in their usage patterns, activity preferences, perceptions of problems, and attitudes about management practices. Small differences were present, however, and managers need to be aware of these differences when integrating recreation with other forest activities.

Keywords: Dispersed recreation, recreation surveys, recreation management, human behavior.

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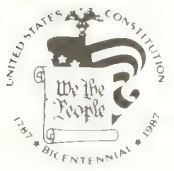

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Estimates of Site Index and Height Growth for Douglas-Fir in High-Elevation Forests of the Oregon-Washington Cascade Range: Curves and Tables for Field Application

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Abstract

DeMars, Donald J.; Herman, Francis R. 1987. Estimates of site index and height growth for Douglas-fir in high-elevation forests of the Oregon-Washington Cascade Range: curves and tables for field application. Res. Pap. PNW-RP-378. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 16 p.

Estimation equations for height growth and site index were derived from stem-analysis data of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) in the high-elevation forests of the Cascade Range in Oregon and Washington. Two sets of height-growth and site-index estimation curves and tables produced from previously published equations are presented—one set with U.S. customary units of measure and another set with metric units. These curves and tables were designed for use in the field by forest managers.

Keywords: Site index, increment (height), stem analysis, stand age, altitude (-site, Douglas-fir (coast), Oregon (Cascade Range), Washington (Cascade Range).

Summary

Equation and curves for height growth and site index were developed from stem-analysis data for selected, dominant Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) trees collected at 52 locations between McKenzie Pass in central Oregon and Stevens Pass in north-central Washington. This paper presents previously published equations in tabular and graphic form suitable for field use.

Curves were based on the tallest, undamaged dominant in 0.25-acre (0.1-ha) plots from unmanaged stands. Trees with similar attributes should be selected when the site index of an upper slope forest stand is estimated.

Estimation curves for site index obtained by regressing site index on height and age differed from estimation curves for height growth obtained by regressing height on site index and age. Site-index curves should be used to predict the height of stands at the index age, given present age and height; curves for height growth should be used to predict expected heights of Douglas-fir at different ages for stands of a given site index.

Both the site-index curves and the height-growth curves will serve as a basis for developing growth and yield estimates for Douglas-fir in high-elevation forests of the Cascade Range in Oregon and Washington.

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Introduction

This paper presents estimation curves for height growth and site index in tabular and graphic form for Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) in the high-elevation forests of the Cascade Range in Oregon and Washington. The curves are based on equations previously presented by Curtis and others (1974a). Methods of analysis were those used for both Douglas-fir and noble fir (*Abies procera* Rehd.) (Curtis and others 1974a, 1974b; Herman and others 1978.) Equations, curves, and tables are presented in both U.S. customary and metric units.

The equations and curves were developed from stem-analysis data for selected dominant Douglas-fir trees collected at 52 locations between McKenzie Pass in central Oregon and Stevens Pass in north-central Washington (fig. 1). All locations were in unmanaged stands, mainly old growth in the *Abies amabilis* zone of Franklin and Dyrness (1973). Data from section trees were also collected for associated species: curves for associated noble fir were developed by Herman and others (1978), and Douglas-fir curves were presented by Curtis and others (1974b). Site-index and height curves for other species are planned.

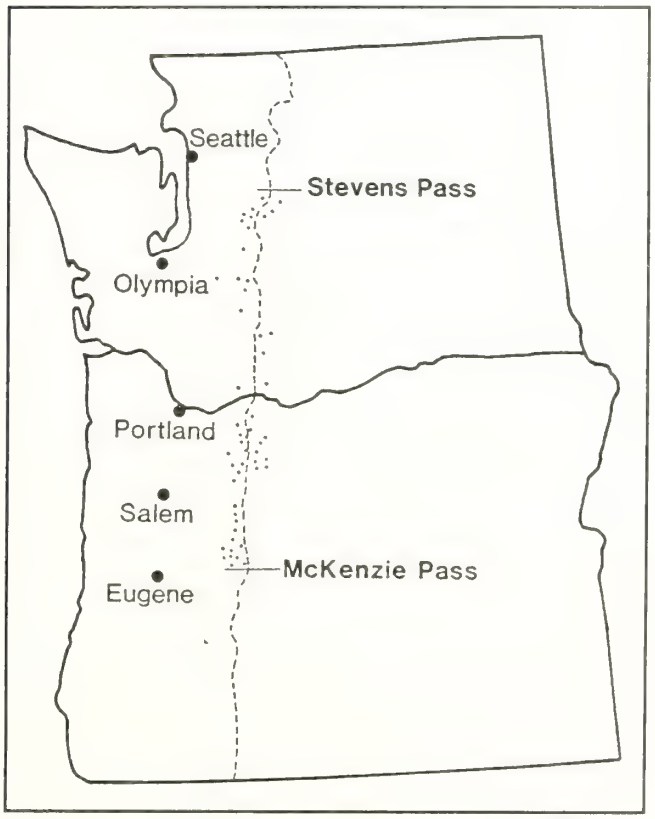

Figure 1—Geographic distribution of the Douglas-fir selected for stem analysis and used in the development of estimation curves for height growth and site index. All plot locations are in unmanaged stands, mainly old growth within the *Abies amabilis* zone of Franklin and Dyrness (1973).

Data

An area of uniform site and stand conditions was selected, usually about 0.25-acre (0.1-ha) within a stand or group of trees in which the dominants were judged to be of one age class. The tallest dominant or codominant tree of each species present was selected and felled for stem analysis. Trees with indicators of rot and obvious defects, such as thin crowns, were avoided as were trees with stag, forked, or broken tops and bent and crooked stems. Sections were cut at the stump (stump height varied), at 4.5 feet (1.37 m), and at intervals up the stem (usually 18 feet [5.5 m]) in the merchantable portion of large trees and at shorter intervals in small trees and tops.

For each tree, a graph of height over age was plotted by computer, and the height-growth pattern of the tree was examined for signs of early suppression or history of past top damage. Because Douglas-fir is a shade-intolerant species, few trees showed abnormal early growth reduction, and only a few trees were rejected for a history of top damage. In the following tabulation, data from trees used in the analysis are summarized by number of sample trees present at successive breast height ages (age bh) (Curtis and others 1974b):

Age bh	Number of trees
10-80	52
100	49
150	47
200	40
250	31
300	10
350	7
400	4

The number of trees by classes of height attained at age 100 (H100) is given in figure 2.

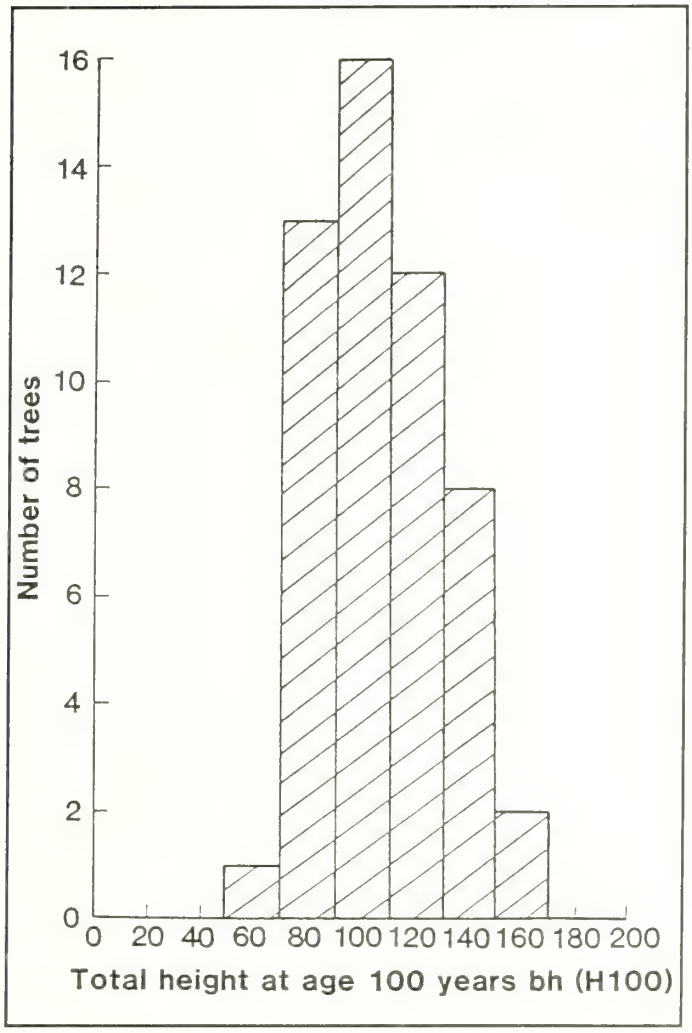

Figure 2—Number of Douglas-fir trees used in analysis sample by classes of H100 (attained height at age 100 years bh) (data from Curtis and others 1974b).

Analysis

Interpolated values of height at successive 10-year intervals of age bh were the values used in the analysis. With minor modifications, the analysis follows the methods used with noble fir (Curtis and others 1974a, Herman and others 1978).

Two symbols used in the discussion and equations need to be defined:

- H100 is individual sample-tree height (in feet) at age 100 bh; it is an estimate of site index.

- H is total height of the tree at any specified age bh (age bh is the number of annual rings at 4.5 feet on the stem).

To fit equations, we subtracted 4.5 feet (1.37 m) from H100 and H to provide a common origin for scales of height and age at bh.

Equations for Height Growth

The regression (H - 4.5) = a + b (H100 - 4.5), where 4.5 feet [1] is breast height, was fitted to data for individual 10-year intervals of age bh. These regressions provided estimates of H for successive intervals of H100 that, when connected, gave unsmoothed trends over age which were used as guides in selecting suitable equation forms (Curtis and others 1974a, 1974b; Heger 1968). The standard errors of estimates (SEE) from the regressions were used as the basis for the weighting factor in subsequent computations. Details of the analysis are given in Curtis and others (1974b).

Equations for height estimation are:

Equation 1, in feet:

$$H = 4.5 + \frac{(H100-4.5)}{[a+b/(H100-4.5)+c(A^n)+d/(H100-4.5)(A^n)]} \quad ;$$

where:

A = age bh,

a = 0.6192,

b = –5.3394,

c = 240.29,

d = 3368.9,

n = –1.4,

H = height of tree in feet, and

H100 = total height (feet) of an individual tree at age 100 bh, which is an estimate of site index.

Standard error of estimate of the transformed variable w (H–4.5) was 0.954.

Height estimates calculated by this equation are given in table 1, and corresponding height-growth curves are shown in figure 3.

---

[1] The regressions expressed in metric equivalents:

$$(H_m - 1.37) = a + b(H100_m - 1.37);$$

where 1.37 meters is breast height.

Regression coefficients appearing in equations are changed where necessary to produce valid metric expressions. Curves expressed in metric units will be slightly different in reference height; that is, site-index curves for 32 in meters have no exact counterpart in selected curves for U.S. customary units. Separate equations are therefore given for feet and for meters.

Table 1—Expected heights in feet for indicated ages at breast height (bh) for values of H100 (total height at index age 100 years bh) [1]

Age bh	Height at index age 100										
	60	70	80	90	100	110	120	130	140	150	160
Years	*Feet*										
10	9	10	11	12	13	14	15	16	17	18	19
20	16	18	20	22	25	27	29	32	34	36	39
30	22	26	30	34	37	41	45	48	52	56	60
40	29	34	39	44	49	54	59	64	69	74	79
50	36	42	48	54	60	66	72	79	85	91	97
60	42	49	56	63	70	77	84	92	99	106	113
70	47	55	63	71	79	87	95	103	111	119	127
80	52	60	69	78	87	96	104	113	122	131	140
90	56	66	75	84	94	103	113	122	132	141	150
100	60	70	80	90	100	110	120	130	140	150	160
110	64	74	84	95	106	116	126	137	148	158	168
120	67	78	88	100	110	121	132	143	154	165	176
130	70	81	92	104	115	126	137	149	160	171	183
140	72	84	95	107	119	130	142	154	165	177	189
150	74	86	98	110	122	134	146	158	170	182	194
160	77	89	101	113	126	138	150	162	174	187	199
170	78	91	103	116	128	141	153	166	178	191	203
180	80	93	106	118	131	144	156	169	182	194	207
190	82	95	108	120	133	146	159	172	185	198	211
200	83	96	109	122	136	149	162	175	188	201	214
210	85	98	111	124	138	151	164	177	190	204	217
220	86	99	113	126	139	153	166	180	193	206	220
230	87	101	114	128	141	155	168	182	195	209	222
240	88	102	115	129	143	156	170	184	197	211	224
250	89	103	117	130	144	158	172	185	199	213	227
260	90	104	118	132	145	159	173	187	201	215	229
270	91	105	119	133	147	161	174	188	202	216	230
280	92	106	120	134	148	162	176	190	204	218	232
290	92	107	121	135	149	163	177	191	205	220	234
300	93	107	122	136	150	164	178	192	207	221	235
310	94	108	122	136	151	165	179	194	208	222	237
320	94	109	123	137	152	166	180	195	209	224	238
330	95	109	124	138	152	167	181	196	210	225	239
340	96	110	124	139	153	168	182	197	211	226	240
350	96	110	125	140	154	168	183	198	212	227	241
360	97	111	126	140	155	169	184	198	213	228	242
370	97	112	126	141	155	170	185	199	214	229	243
380	98	112	127	141	156	171	185	200	215	229	244
390	98	112	127	142	156	171	186	201	216	230	245
400	98	113	128	142	157	172	187	201	216	231	246

[1] From equation 1 (in feet). Values correspond to height-growth curves shown in figure 3. Estimates for ages greater than 270 years bh are extrapolations of the data base.

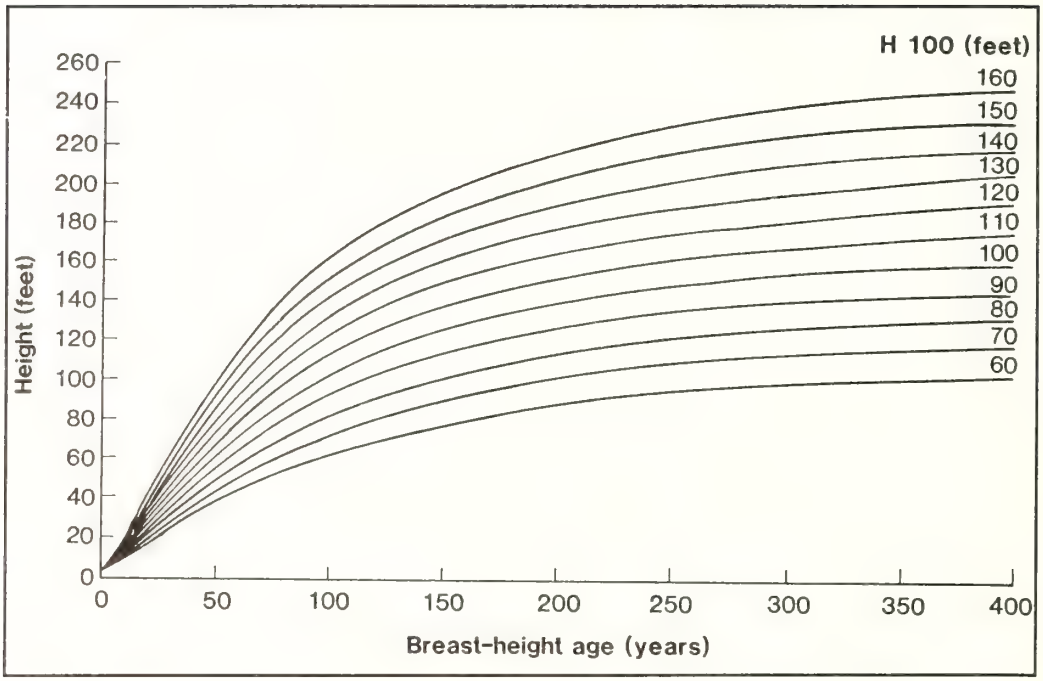

Figure 3—Height-growth curves for Douglas-fir (in feet) corresponding to equation 1 (in feet). These curves express the pattern of height growth of dominant trees in relation to age, within even-aged stands. The curves should be used to express height development in the construction of yield functions representing average development of even-aged stands actually attaining specified heights at index age 100 (site indices).

Equation 1, in meters:

$$H_m = 1.3716 + [a+b / (H100_m - 1.3716) + c(A^n) + d /(H100_m - 1.3716)(A^n)] ;$$

where:

A = age bh,

a = 0.6192,

b = –1.6274,

c = 240.29,

d = 1026.83,

n = –1.4,

H_m = height of tree in meters, and

$H100_m$ = total height (meters) of an individual tree at age 100 bh, which is an estimate of site index.

Height estimates calculated by this equation are given in table 2, and corresponding metric height-growth curves are shown in figure 4.

Table 2—Expected heights in meters for indicated ages at breast height (bh) for values of $H100_m$ (total height at index age 100 years bh)[1]

Age	Height at index age 100										
bh	20	23	26	29	32	35	38	41	44	47	50
Year	*Meters*										
10	2.9	3.2	3.5	3.8	4.0	4.3	4.6	4.9	5.2	5.5	5.8
20	5.1	5.8	6.5	7.2	7.9	8.6	9.3	10.0	10.7	11.4	12.1
30	7.5	8.6	9.7	10.8	11.9	13.0	14.1	15.3	16.4	17.5	18.6
40	9.8	11.3	12.7	14.2	15.7	17.2	18.7	20.2	21.7	23.2	24.8
50	11.9	13.7	15.6	17.4	19.3	21.1	23.0	24.8	26.6	28.5	30.3
60	13.9	16.0	18.2	20.3	22.4	24.6	26.7	28.9	31.0	33.2	35.3
70	15.7	18.1	20.5	22.9	25.3	27.7	30.1	32.5	34.9	37.3	39.7
80	17.3	19.9	22.5	25.2	27.8	30.4	33.1	35.7	38.3	41.0	43.6
90	18.7	21.5	24.4	27.2	30.0	32.9	35.7	38.5	41.3	44.2	47.0
100	20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0	44.0	47.0	50.0
110	21.2	24.3	27.5	30.6	33.8	36.9	40.1	43.2	46.4	49.5	52.7
120	22.2	25.5	28.8	32.0	35.3	38.6	41.9	45.2	48.4	51.7	55.0
130	23.1	26.5	29.9	33.3	36.7	40.1	43.5	46.9	50.3	53.7	57.1
140	24.0	27.5	31.0	34.5	38.0	41.5	45.0	48.5	52.0	55.5	59.0
150	24.7	28.3	31.9	35.5	39.1	42.7	46.3	49.9	53.5	57.0	60.6
160	25.4	29.1	32.8	36.4	40.1	43.8	47.4	51.1	54.8	58.5	62.1
170	26.1	29.8	33.5	37.3	41.0	44.8	48.5	52.3	56.0	59.7	63.5
180	26.6	30.4	34.2	38.0	41.9	45.7	49.5	53.3	57.1	60.9	64.7
190	27.2	31.0	34.9	38.7	42.6	46.5	50.3	54.2	58.1	62.0	65.8
200	27.6	31.5	35.5	39.4	43.3	47.2	51.1	55.1	59.0	62.9	66.8
210	28.1	32.0	36.0	40.0	43.9	47.9	51.9	55.8	59.8	63.8	67.8
220	28.5	32.5	36.5	40.5	44.5	48.5	52.5	56.6	60.6	64.6	68.6
230	28.9	32.9	36.9	41.0	45.0	49.1	53.2	57.2	61.3	65.3	69.4
240	29.2	33.3	37.4	41.4	45.5	49.6	53.7	57.8	61.9	66.0	70.1
250	29.5	33.6	37.7	41.9	46.0	50.1	54.3	58.4	62.5	66.6	70.8
260	29.8	34.0	38.1	42.3	46.4	50.6	54.7	58.9	63.1	67.2	71.4
270	30.1	34.3	38.4	42.6	46.8	51.0	55.2	59.4	63.6	67.8	72.0
280	30.4	34.6	38.8	43.0	47.2	51.4	55.6	59.8	64.0	68.3	72.5
290	30.6	34.8	39.0	43.3	47.5	51.8	56.0	60.2	64.5	68.7	73.0
300	30.8	35.1	39.3	43.6	47.8	52.1	56.4	60.6	64.9	69.2	73.4
310	31.0	35.3	39.6	43.8	48.1	52.4	56.7	61.0	65.3	69.6	73.9
320	31.2	35.5	39.8	44.1	48.4	52.7	57.0	61.3	65.6	70.0	74.3
330	31.4	35.7	40.0	44.3	48.7	53.0	57.3	61.6	66.0	70.3	74.7
340	31.6	35.9	40.2	44.6	48.9	53.3	57.6	61.9	66.3	70.7	75.0
350	31.8	36.1	40.4	44.8	49.1	53.5	57.9	62.2	66.6	71.0	75.3
360	31.9	36.3	40.6	45.0	49.4	53.7	58.1	62.5	66.9	71.3	75.7
370	32.1	36.4	40.8	45.2	49.6	54.0	58.3	62.7	67.1	71.5	75.9
380	32.2	36.6	41.0	45.4	49.8	54.2	58.6	63.0	67.4	71.8	76.2
390	32.3	36.7	41.1	45.5	49.9	54.4	58.8	63.2	67.6	72.1	76.5
400	32.5	36.9	41.3	45.7	50.1	54.5	59.0	63.4	67.9	72.3	76.7

[1] From equation 1 (in meters). Values correspond to height-growth curves shown in figure 4. Estimates for ages greater than 270 years bh are extrapolations of the data base.

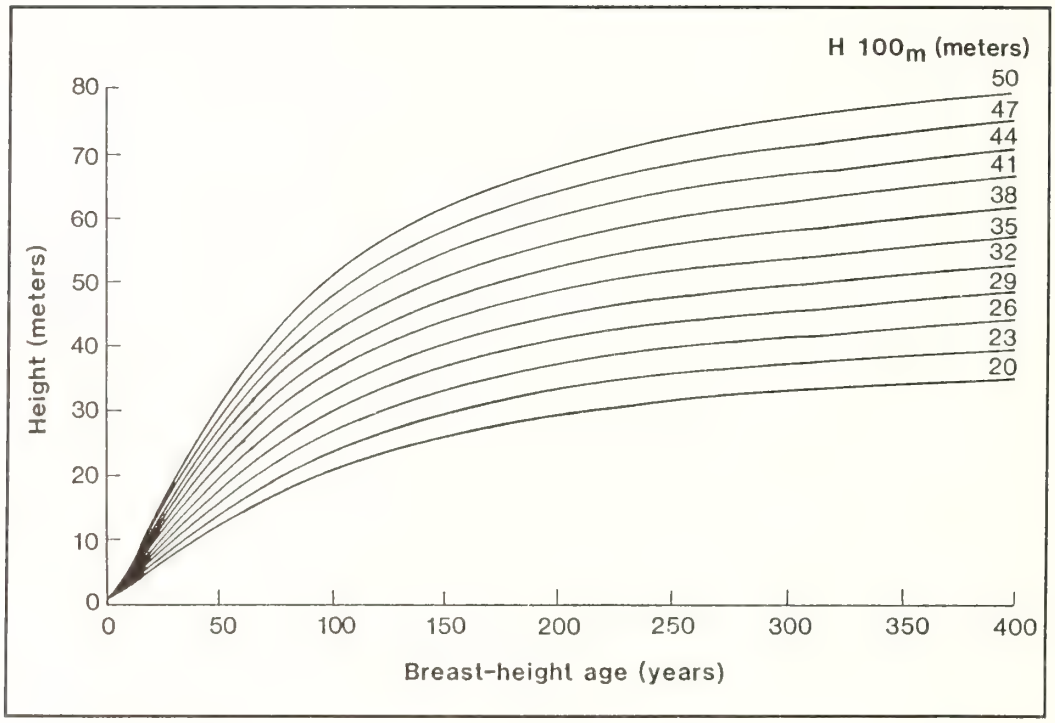

Figure 4—Height-growth curves for Douglas-fir (in meters) corresponding to equation 1 (in meters). These curves express the pattern of height growth of dominant trees in relation to age, within even-aged stands. The curves should be used to express height development in the construction of yield functions representing average development of even-aged stands actually attaining specified heights at index age 100 (site indices).

Equations for Site Index

Preliminary regression equations $(H100 - 4.5) = a + b\,(H - 4.5)$ and $(H100 - 4.5) = a + b\,(H - 4.5) + c(H - 4.5)^2$ were fitted to data for individual, successive 10-year intervals of age bh. Estimated regression coefficients were plotted over age and the resulting graphs examined to determine if regression coefficients are related to age bh. Identified trends were used as guides in the selection of equation models for expressing the $H100 = f\,(H, \text{age})$ relationship for all combined data.

We encountered difficulties when we tried to develop a single site-index estimation equation for the complete data set because of the wide range in ages and the small number of data points in the upper portion of the age range. To overcome these difficulties and to simplify curve fitting, we divided the pooled data into two groups: (1) ages less than or equal to 100 years bh, and (2) ages over 100 years bh. Separate, weighted regression equations were fitted to each data group. Both equations were conditioned so that H100 = H at age bh = 100 (Curtis and others 1974b).

Equation 2, in feet (ages≤100 years bh):

$$(H100) = 4.5 + a + b(H - 4.5) ;$$

where:

$$a = 0.01006(100\text{-}A)^2 , \text{ and}$$

$$b = 1.0 + 0.00549779\ (100 - A) + 1.46842 \times 10^{-14}\ (100 - A)^7 .$$

Standard error of estimate of the transformed variable, w(H100-H), was 0.241.[2]

Corresponding numerical values are shown in table 3, and curves in figure 5, for ages bh of 10 through 100 years.

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[2] w(H100−H) was the dependent variable used to derive the equation (Curtis and others 1974b).

Table 3—Ages bh and total heights in feet corresponding to indicated estimates of H100 (height at index age 100 years bh)[1]

Age bh	Height at index age 100										
	60	70	80	90	100	110	120	130	140	150	160
Years	*Feet*										
10	[2] –7	–2	2	6	11	16	20	25	29	34	38
20	0	5	11	17	22	28	34	40	45	51	57
30	9	15	22	29	35	42	49	55	62	69	75
40	19	26	33	41	48	55	62	70	77	84	92
50	28	36	44	52	59	67	75	83	90	98	106
60	37	45	53	61	70	78	86	94	102	110	119
70	44	53	62	70	79	87	96	104	113	122	130
80	51	60	69	78	87	96	105	114	123	132	141
90	56	66	75	85	94	104	113	122	132	142	151
100	60	70	80	90	100	110	120	130	140	150	160
110	63	74	85	95	106	116	127	138	148	159	169
120	66	77	88	99	110	121	132	143	154	166	176
130	68	80	91	103	114	126	137	148	160	172	183
140	70	82	94	106	118	130	142	153	165	177	189
150	72	84	97	109	121	133	146	158	170	182	194
160	74	86	99	111	124	136	149	162	174	187	199
170	75	88	101	114	126	139	152	165	178	191	204
180	76	89	102	116	129	142	155	168	182	195	208
190	77	90	104	117	131	144	158	172	185	199	212
200	77	91	105	119	133	147	161	175	188	202	216
210	78	92	107	121	135	149	164	178	192	206	220
220	79	94	108	123	137	152	166	181	195	210	224
230	80	95	110	124	139	154	169	184	198	213	228
240	81	96	111	126	142	157	172	187	202	217	232
250	82	98	113	128	144	159	174	190	205	220	236
260	83	99	114	130	146	162	177	193	208	224	240
270	84	100	116	132	148	164	180	196	212	228	244
280	85	102	118	134	150	166	183	199	215	231	248
290	86	103	119	136	152	169	186	202	218	235	252
300	88	104	121	138	155	172	188	205	222	239	255
310	89	106	123	140	157	174	191	208	225	242	259
320	90	107	124	142	159	176	194	211	228	246	263
330	91	109	126	144	161	179	197	214	232	250	267
340	92	110	128	146	164	182	199	217	235	253	271
350	93	112	130	148	166	184	202	220	238	257	275
360	94	113	131	150	168	187	205	223	242	260	279
370	96	114	133	152	170	189	208	226	245	264	283
380	97	116	135	154	173	192	211	230	248	268	286
390	98	117	136	156	175	194	213	233	252	271	290
400	99	119	138	158	177	197	216	236	255	275	294

[1] Values for ages under 100 are from equation 2 (in feet); those for ages over 100 are from equation 3 (in feet). Corresponding site-index estimation curves are shown in figure 5. Estimates for ages greater than 270 years bh are extrapolations of the data base.

[2] Biologically impossible values indicate merely that no height actually observable at that age justifies the indicated estimate of H100 (Curtis and others 1974a).

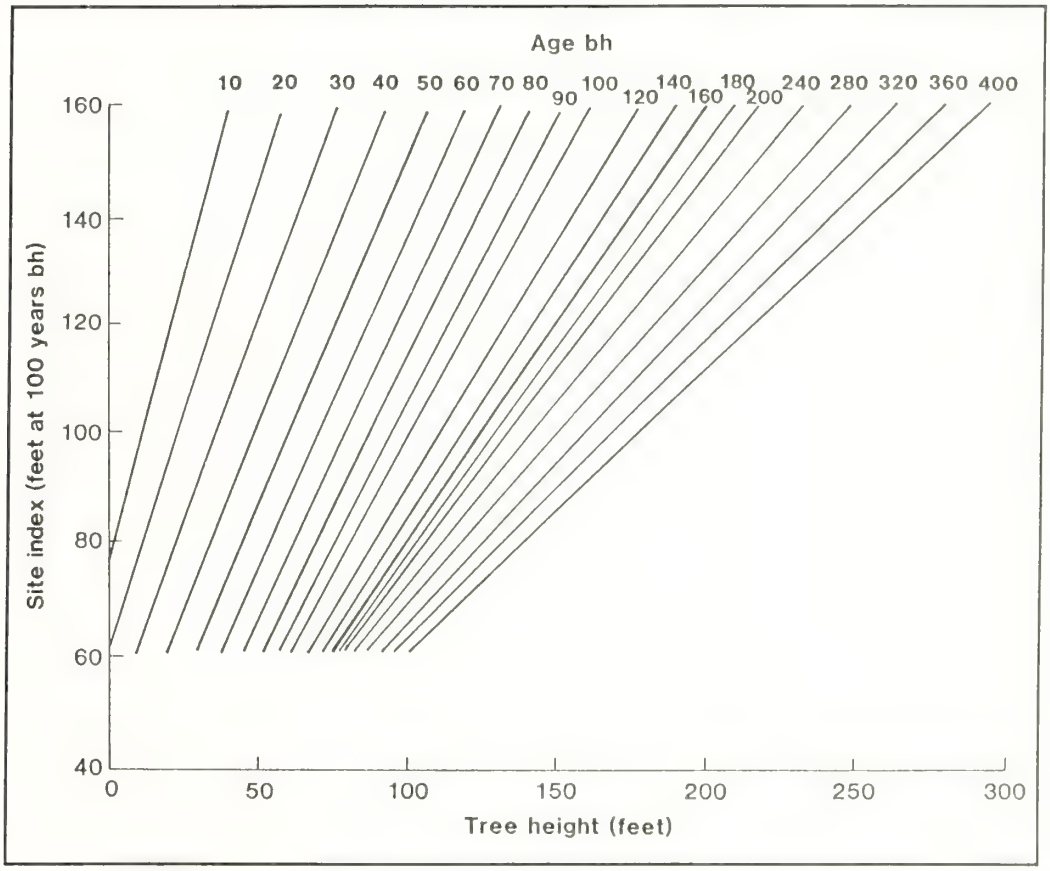

Figure 5—Estimation curves for site index for Douglas-fir. Curves for ages less than 100 years bh correspond to equation 2 (in feet); those for ages over 100 years bh correspond to equation 3 (in feet). Use these curves for estimating site index; that is, for estimating height at 100 years bh of a tree observed at some other age.

Equation 2, in meters (ages ≤ 100 years bh):

$$H100_m = 1.3716 + a + b\,(H_m - 1.3716)\ ;$$

where:

$$a = (0.00305\,(100-A)^2),\ \text{and}$$

$$b = [1.0 + 0.00549779\,(100-A) + 1.46842 * 10^{-14}\,(100-A)^7\,].$$

Corresponding metric values are shown in table 4 and curves in figure 6 for ages bh of 10 through 100 years.

Table 4—Ages bh and total heights in meters corresponding to indicated estimates of $H100_m$ (height at index age 100 years bh) [1]

Age bh	Height at index age 100										
	20	23	26	29	32	35	38	41	44	47	50
Years	*Meters*										
10	[2] –1.3	0.0	1.3	2.7	4.1	5.4	6.8	8.2	9.5	10.9	12.3
20	0.9	2.6	4.3	6.0	7.7	9.4	11.2	12.9	14.6	16.3	18.0
30	3.8	5.8	7.8	9.8	11.8	13.8	15.8	17.8	19.8	21.7	23.7
40	7.0	9.1	11.3	13.5	15.7	17.9	20.1	22.3	24.5	26.6	28.8
50	9.9	12.3	14.6	16.9	19.3	21.6	23.9	26.3	28.6	30.9	33.2
60	12.6	15.1	17.5	20.0	22.4	24.9	27.3	29.8	32.3	34.7	37.2
70	15.0	17.6	20.2	22.7	25.3	27.9	30.4	33.0	35.6	38.2	40.7
80	17.1	19.8	22.5	25.2	27.9	30.6	33.3	36.0	38.7	41.4	44.1
90	18.7	21.6	24.4	27.3	30.1	33.0	35.8	38.6	41.5	44.3	47.2
100	20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0	44.0	47.0	50.0
110	21.1	24.3	27.5	30.7	33.9	37.0	40.2	43.4	46.6	49.8	53.0
120	22.0	25.3	28.6	31.9	35.3	38.6	41.9	45.2	48.5	51.9	55.2
130	22.8	26.2	29.6	33.1	36.5	40.0	43.4	46.9	50.3	53.7	57.2
140	23.5	27.0	30.6	34.1	37.7	41.3	44.8	48.4	51.9	55.5	59.0
150	24.1	27.8	31.4	35.1	38.8	42.4	46.1	49.8	53.4	57.1	60.8
160	24.6	28.4	32.1	35.9	39.7	43.5	47.2	51.0	54.8	58.6	62.3
170	25.0	28.9	32.8	36.6	40.5	44.4	48.3	52.1	56.0	59.9	63.8
180	25.4	29.3	33.3	37.3	41.3	45.2	49.2	53.2	57.2	61.1	65.1
190	25.7	29.7	33.8	37.9	42.0	46.0	50.1	54.2	58.2	62.3	66.4
200	26.0	30.2	34.3	38.5	42.6	46.8	51.0	55.1	59.3	63.5	67.6
210	26.3	30.6	34.8	39.1	43.3	47.6	51.8	56.1	60.4	64.6	68.9
220	26.6	31.0	35.3	39.7	44.0	48.4	52.7	57.1	61.4	65.8	70.1
230	27.0	31.4	35.8	40.3	44.7	49.2	53.6	58.0	62.5	66.9	71.3
240	27.3	31.8	36.4	40.9	45.4	49.9	54.5	59.0	63.5	68.0	72.6
250	27.7	32.3	36.9	41.5	46.1	50.7	55.3	60.0	64.6	69.2	73.8
260	28.0	32.7	37.4	42.1	46.8	51.5	56.2	60.9	65.6	70.3	75.0
270	28.4	33.2	38.0	42.8	47.5	52.3	57.1	61.9	66.7	71.5	76.3
280	28.8	33.7	38.5	43.4	48.3	53.1	58.0	62.9	67.7	72.6	77.5
290	29.2	34.1	39.1	44.0	49.0	53.9	58.9	63.8	68.8	73.8	78.7
300	29.6	34.6	39.6	44.7	49.7	54.7	59.8	64.8	69.9	74.9	79.9
310	29.9	35.1	40.2	45.3	50.4	55.5	60.7	65.8	70.9	76.0	81.1
320	30.3	35.5	40.7	45.9	51.1	56.4	61.6	66.8	72.0	77.2	82.4
330	30.7	36.0	41.3	46.6	51.9	57.2	62.4	67.7	73.0	78.3	83.6
340	31.1	36.5	41.9	47.2	52.6	58.0	63.3	68.7	74.1	79.4	84.8
350	31.5	37.0	42.4	47.9	53.3	58.8	64.2	69.7	75.1	80.6	86.0
360	32.0	37.5	43.0	48.5	54.1	59.6	65.1	70.6	76.2	81.7	87.2
370	32.4	38.0	43.6	49.2	54.8	60.4	66.0	71.6	77.2	82.8	88.4
380	32.8	38.5	44.1	49.8	55.5	61.2	66.9	72.6	78.3	84.0	89.7
390	33.2	38.9	44.7	50.5	56.3	62.0	67.8	73.6	79.3	85.1	90.9
400	33.6	39.4	45.3	51.1	57.0	62.8	68.7	74.5	80.4	86.2	92.1

[1] Values for ages under 100 are from equation 2 (in meters); those for ages over 100 are from equation 3 (in meters). Corresponding site-index estimation curves are shown in figure 6. Estimates for ages greater than 270 years bh are extrapolations of the data base.

[2] Biologically impossible values indicate merely that no height actually observable at that age justifies the indicated estimate of $H100_m$ (Curtis and others 1974a).

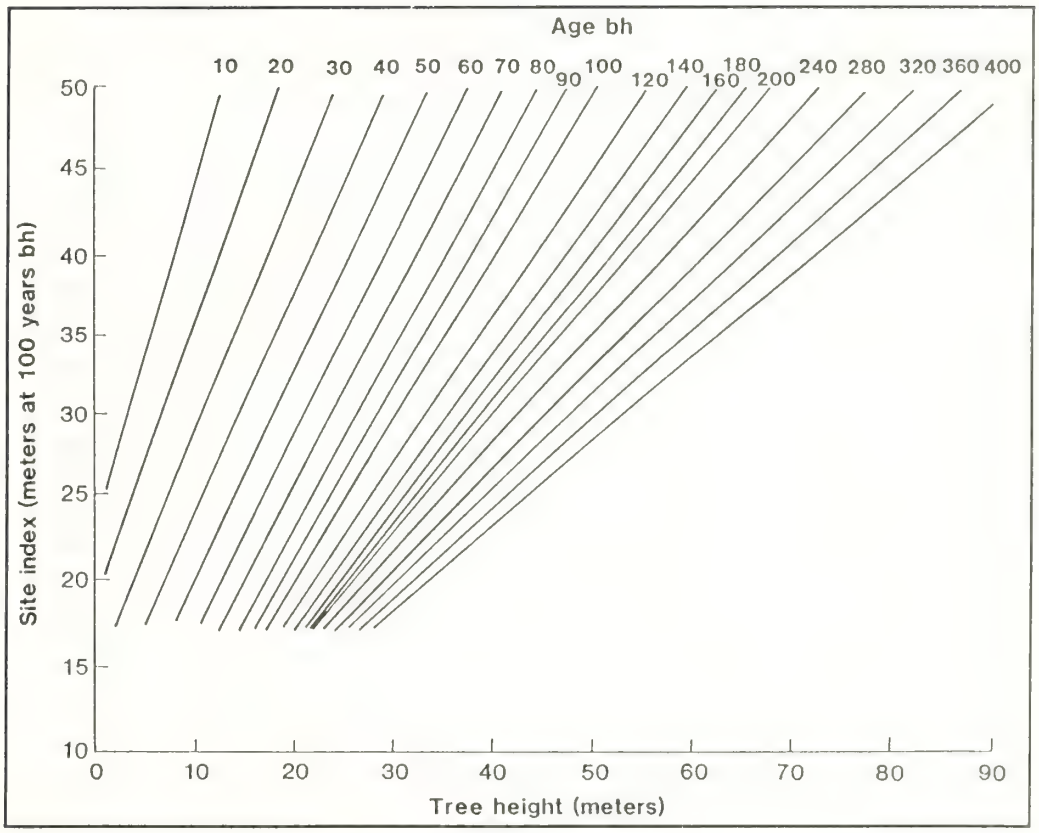

Figure 6—Estimation curves for site index for Douglas-fir. Curves for ages less than 100 years bh correspond to equation 2 (in meters); those for ages over 100 bh correspond to equation 3 (in meters). Use these curves for estimating site index; that is, for estimating height at 100 years bh of a tree observed at some other age.

Equation 3, in feet (ages > 100 years bh):

$$H100 = 4.5 + [7.6672\,(e^{-0.95\,(100/(A-100))^2})] + [1.0 - 0.730948\,(\log_{10} A - 2.0)^{0.8}]\,[H - 4.5].$$

Standard error of estimate of the transformed variable, w(H100-H), was 1.008.

Corresponding numerical values are shown in table 3, and curves in figure 5. for ages 100 + years bh.

Equation 3, in meters (ages >100 years bh):

$$H100_m = 1.3716 + [2.33709\,(e^{-0.95\,(100/(A-100))^2})] + [1.0 - 0.730948\,(\log_{10} A - 2.0)]^{0.8}\,[H_m - 1.3716].$$

Corresponding metric values are shown in table 4 and curves in figure 6, for ages 100+ years bh.

Discussion

Primary reasons for selecting 100 years bh as the index age were (1) the growth characteristics of Douglas-fir at high elevations and (2) the relatively long rotations that seem probable given the growth characteristics of the species.

As pointed out by Curtis and others (1974a), the dependent variable used to develop site-index equations should be different from the one used to develop height-growth equations. Corresponding curves from these equations are appropriate for different uses.

Estimation Curves for Height Growth

Height curves presented in this paper express the pattern of height growth of the tallest dominant Douglas-fir trees in relation to age, within even-aged stands. "H" was the dependent variable used to fit equations. Appropriate uses for these curves include estimating height development of stands actually attaining specified heights at index age (site index) and estimating stand-height development in the construction of yield tables.

Figures 3 and 4 demonstrate the ability of the tallest undamaged Douglas-fir trees (about 5 trees per acre) to maintain a good rate of height growth at advanced ages. Curtis and others (1974b) compared the height-growth curves for high elevation to two sets of height-growth curves (King 1966; McArdle and others 1930, 1961) developed for low-elevation Douglas-fir and found their shapes to be quite different. Although no data are available, such differences in height growth must be associated with similar differences in volume growth.

Estimation Curves for Site Index

H100 was the dependent variable used to fit site-index equations. For ages other than index age, the site-index estimation curves shown in figures 5 and 6 provide better estimates of height at index age than does the traditional inverted form of height-growth curves. Thus, the primary use of these curves should be to estimate stand height at index age 100.

Possible Bias

The height-growth and the site-index curves appear to be unbiased. Plots were established in carefully chosen stands that were evaluated as even-aged. Within these stands, only the tallest, undamaged, dominant tree of each species was selected for stem analysis. Trees that were sectioned and later found to have unusual growth patterns (caused by broken tops, suppression, insects and disease, or other damaging agents) were either replaced or discarded.

A possible bias could exist, even after we used these careful selection criteria, if undetected effects of broken tops, suppression, insects and disease, or other damaging agents were present or if the tallest trees selected at the time of cutting were not always the tallest throughout the life of the stand. As pointed out by Dahms (1963), bias can be introduced by such shifts in relative crown positions of sample trees over time. These shifts probably would not materially alter the shape of the curves within the age range of 100-250 years but could introduce bias at the younger ages.

Because of the shade intolerance of upper slope Douglas-fir, bias caused by shifts in relative crown position is not expected.

Application of Curves

The following criteria for applying the noble fir curves presented by Herman and others (1978) are also valid for the Douglas-fir curves:

- Trees must be growing in even-aged stands.
- Each Douglas-fir selected for site-index estimation must be the tallest, undamaged, dominant tree on an area of about 0.25 acre.
- Trees that are of a different age class from surrounding trees should be avoided.
- Curves are applicable to upper elevation forests in the Cascade Range between McKenzie Pass in Oregon and Stevens Pass in Washington.

When estimating the site index for a stand:

- Select a sample of undamaged, dominant Douglas-fir trees well distributed over the area (about 4 or 5 per acre).
- Determine total height and age bh for each tree.
- Use values from step 2 and equations 2 and 3, tables 3 and 4, or figures 5 and 6.
- Calculate the mean of the site-index values to estimate the site index of the stand.

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Estimation equations for height growth and site index were derived from stem-analysis data of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) in the high-elevation forests of the Cascade Range in Oregon and Washington. Two sets of height-growth and site-index estimation curves and tables produced from previously published equations are presented—one set with U.S. customary units of measure and another set with metric units. These curves and tables were designed for use in the field by forest managers.

Keywords: Site index, increment (height), stem analysis, stand age, altitude (-site, Douglas-fir (coast), Oregon (Cascade Range), Washington (Cascade Range).

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Hydrologic and Climatic Changes in Three Small Watersheds After Timber Harvest

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Abstract

Fowler, W.B.; Helvey, J.D.; Felix, E.N. 1987. Hydrologic and climatic changes in three small watersheds after timber harvest. Res. Pap. PNW-RP-379. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 13 p.

No significant increases in annual water yield were shown for three small watersheds in northeastern Oregon after shelterwood cutting (30-percent canopy removal, 50-percent basal area removal) and clearcutting. Average maximum air temperature increased after harvest and average minimum air temperature decreased by up to 2.6 °C. Both maximum and minimum water temperatures decreased slightly in two streams as compared with the control stream. Wind passage and velocities increased dramatically with removal of the forest cover. Both snow depth and snowpack water content increased in clearcuttings.

Keywords: Logging effects, hydrologic analysis, climatic change, watershed management, Oregon (Blue Mountains), Blue Mountains— Oregon.

Summary

This case study summarizes the effects of a 30-percent canopy-removal shelterwood cutting and clearcuttings ranging from 0.8 to 8.5 ha on some hydrologic and climatic variables of the High Ridge Evaluation Area. This area consists of four small (24.4 to 118.1 ha) calibrated watersheds within the larger Umatilla National Forest barometer watershed in northeastern Oregon. Areas were harvested in 1976 after 9 years of prelogging calibration. Changes in water yield were evaluated for the years 1976 through 1982; no significant increases in annual water yield were shown. Supplemental analysis reported elsewhere also showed no statistically significant changes in either peak or low flow from these watersheds. Average maximum air temperatures increased up to 2 °C after harvest, while average minimums decreased up to 2.6 °C. Both maximum water temperature and minimum water temperature decreased in two streams as compared with the control stream. Wind passage and velocities increased dramatically with removal of the forest cover. The increased windflow may have modified the water yield response by transporting snow beyond the watershed boundaries, by increasing evaporation from bare soils and snow surfaces, and by increasing sublimation from the snowpack. Both snow depth and snowpack water content increased in clearcuttings.

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Introduction

Timber harvest in the northwestern United States is moving into higher elevations where forests occupy the primary snow catchments and act as regulators of seasonal runoff. The barometer watershed program of the Forest Service, U.S. Department of Agriculture, was designed, in part, to evaluate how forest management in these snow-zone forests influences water yield, sediment production, and streamflow. The hydrology program was initiated in 1965 by the Umatilla National Forest (headquarters at Pendleton, Oregon). In the early 1970's, the Umatilla National Forest and the Forest Service research laboratories at Wenatchee, Washington, and La Grande, Oregon, began joint studies to examine other watershed characteristics, such as climate, water quality (both chemical and biological), vegetation dynamics, and animal behavior. This case study summarizes the effects of clearcutting and shelterwood cutting on the hydrologic and climatic variables associated with the High Ridge Evaluation Area, four small calibrated watersheds within the larger barometer watershed.

A standard technique for determining changes in water yield uses paired watersheds. The selection of one of the four watersheds for a control allowed three treatment-control pairs. Predictive equations for water yield from the treated watersheds are required; such equations are based on pretreatment measurements. Changes in water yield beyond the confidence limits established from the pretreatment analysis suggest treatment effect.

When treatments for these watersheds were developed, an 11-percent (7.5-cm) increase in yield was predicted for the first year. This prediction was based on 58 percent of the watershed area being treated using 8-ha clearcuts. Literature reviewed by Anderson and others (1976) indicated potential yield increases in this forest type of 7.5 to 15.0 cm as a result of using cutting patterns that increase snowpack. For the moister climates of western Oregon, Harr and others (1982) describe annual increases that range from 60 cm on clearcut watersheds to no increase where clearcut patches totaled only 25 percent of the watershed area. Wildfire on Burns Creek watershed (Entiat Experimental Forest, central Washington) caused measured yields minus predicted yields of 7.4, 47.2, and 17.8 cm for the first, second, and third years after burning. The increase in the second year was over 100 percent of what had been predicted, partly because of an exceptionally deep snowpack (Helvey and others 1976).

Fowler and others (1979) describe the baseline hydrology and the climate of the High Ridge watersheds before treatment and discuss some of the expected changes in air and water temperature, wind, and snow accumulation.

The Study

Watershed Characteristics

The study area (fig. 1), consisted of four watersheds 22 km northwest of Elgin in the Blue Mountains of northeastern Oregon. Elevations range from 1439 to 1617 m, and aspect is generally northeast. Slopes in the study area are moderate at 2 to 25 percent.

Soils of the Blue Mountains are described in detail by Geist and Strickler (1978). Soil in the study area is derived from recent volcanic ash (less than 6,700 years old) and is Helter silt loam (Entic Cryandept) deposited over an older residual soil developed from underlying basalt rock. Both the upper and lower soil horizons are silt loams but with different physical properties. Klock and Lopushinsky (1980) report the bulk density to be near 0.65 gm/cm^3 for the upper soil and 1.3 gm/cm^3 for the buried soil. The upper soil has high water-holding capacity. Soils are generally well drained and are up to 1.5 m deep.

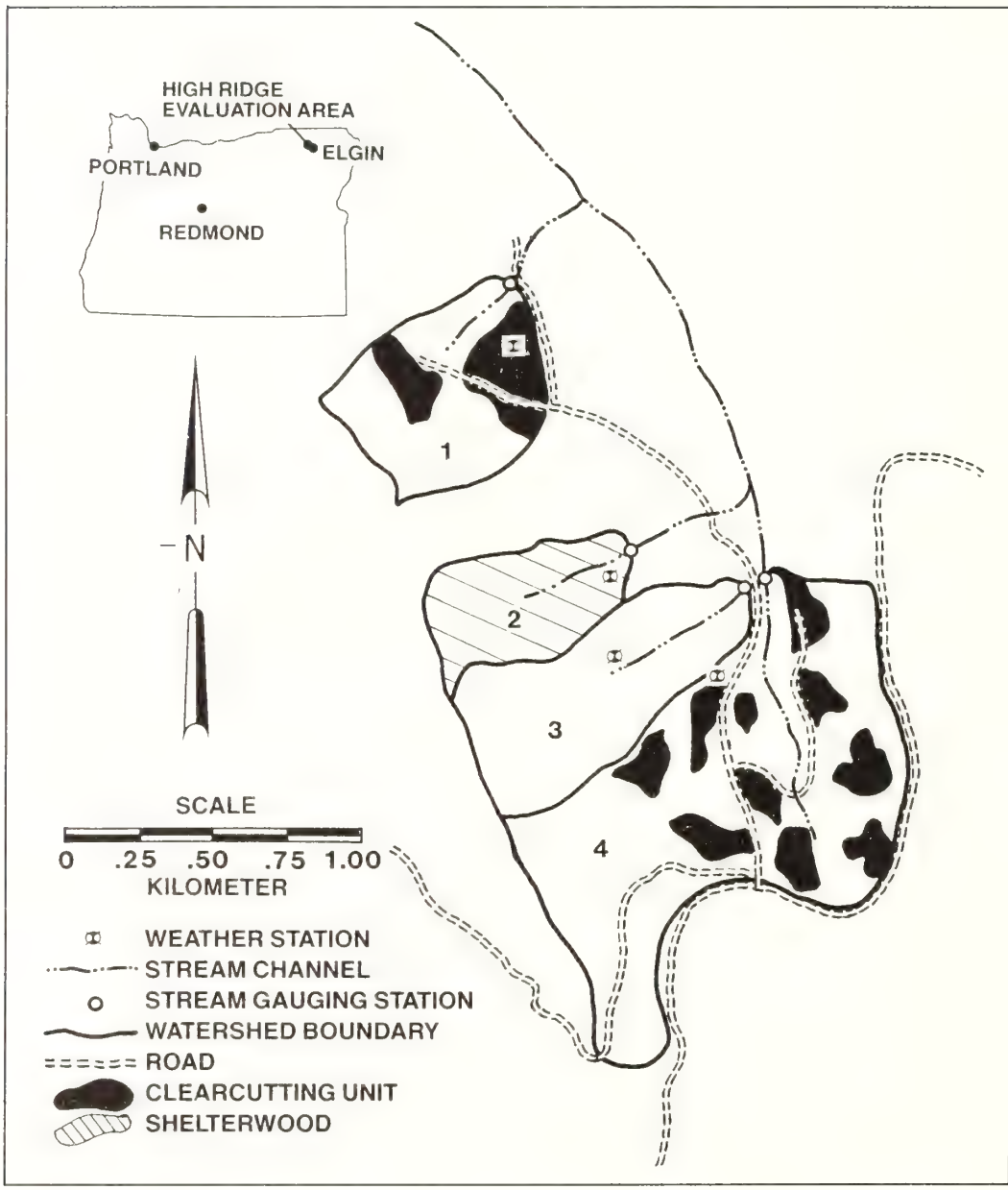

Figure 1--The High Ridge Evaluation Area, Umatilla National Forest, Oregon.

Prelogging vegetation was a dense mixture of grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), subalpine fir (*A. lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), western larch (*Larix occidentalis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.). Grand fir and subalpine fir were the predominant species. Trees were up to 40 m tall and had a maximum age of about 160 years. Primary understory vegetation was Columbia brome (*Bromus vulgaris* (Hook.) Shear), twinflower (*Linnaea borealis* L.), and big huckleberry (*Vaccinium membranaceum* Dougl. ex Hook.).

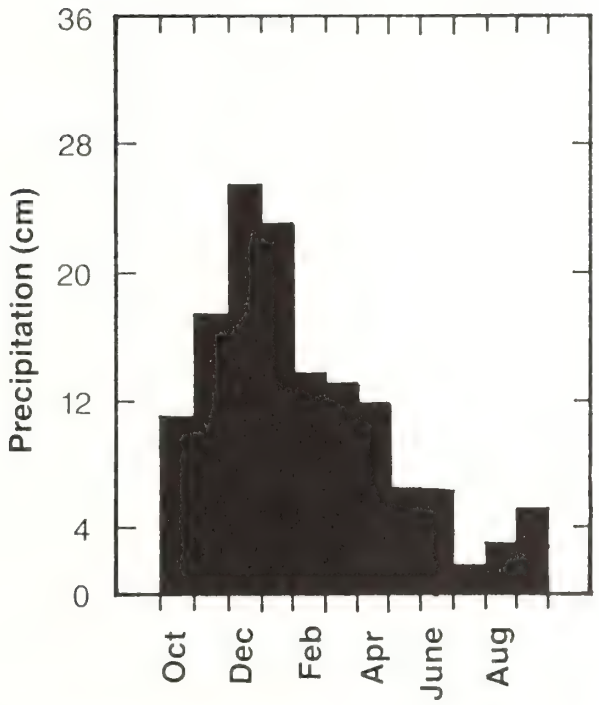

Figure 2--Average monthly precipitation.

Climate and Streamflow

Precipitation occurs primarily during the cool months throughout the Pacific Northwest. Strong airmass contrasts— mild, moist Pacific air and frigid continental polar air— produce vigorous winter storms. The seasonal distribution of precipitation for the High Ridge Evaluation Area as measured in watershed 1 is shown in figure 2. Eighty to 90 percent of the 142.9-cm annual total falls between October 1 and May 31; summers are relatively dry. With decreasing air temperatures in the fall, precipitation changes from rain to snow; a snowpack usually begins to accumulate by late November. The snowpack increases in depth and water content until late March or early April, then gradually melts. Usually the snow is completely melted by early June.

Streamflow has been measured on these watersheds since installation of V-notch weirs in 1966. In contrast to western Oregon, where the streamflow peaks in January or February (Harr and others 1982), peak runoff from these watersheds is in May to July. About 80 percent of the total annual flow occurs in May and June as a result of snowmelt. Flow gradually decreases throughout the summer. Infrequent rain-on-snow runoff events can occur during the winter, and peak daily flows can equal springtime maximums. The seasonal distribution of average daily flow from watershed 1 for 1967 to 1976, the prelogging calibration period, is shown in figure 3. If precipitation and streamflow are measured accurately, and if little deep seepage occurs, the difference between annual precipitation and runoff is the amount of water lost to evapotranspiration. For watersheds 1 to 4, these differences for the calibration period were 105.0, 94.7, 91.5, and 96.1 cm. Reducing evapotranspiration losses by timber harvest was expected to increase water yields. Table 1 lists water-year precipitation and yield for the watersheds.

Table 1—Precipitation and water yield for control (watershed 3) and treatment watersheds

(In centimeters)

Year	Precipitation	Yield			
		Watershed 1	Watershed 2	Watershed 3	Watershed 4
1967	—	320.8	398.0	528.6	407.2
1968	1356.4	173.0	279.4	302.5	278.6
1969	1404.6	430.5	529.6	538.5	511.8
1970	1412.2	442.7	463.6	504.7	438.6
1971	1493.5	538.0	526.8	553.2	475.2
1972	1625.6	388.1	532.4	600.7	576.1
1973	731.5	84.3	216.4	149.4	212.6
1974	1902.5	647.7	792.5	895.4	726.2
1975	1506.2	324.6	510.5	563.4	523.8
1976	1399.5	483.6	720.9	654.3	607.1
1977	843.3	59.7	90.9	166.9	195.6
1978	1409.7	417.6	552.7	476.3	522.5
1979	1021.1	396.2	503.2	472.7	450.3
1980	1191.3	251.2	372.9	355.3	43.7
1981	1229.4	289.6	460.5	436.4	319.0
1982	1618.0	492.3	63.2	714.8	588.5

— = not available.

Maximum temperatures of air (34 °C) and water (16 °C) were measured in these watersheds during the calibration period.[1] A plot of the 1974 maximum air and water temperatures for watershed 4 is shown in figure 4. From 1972 to 1976, the stream temperature in watershed 4 was between 0 and 2 °C for 59.5 percent of the time.

For six winters during the calibration period, no significant difference in snow depth at near-maximum accumulation occurred among plots in the several watersheds. The within-plot variability was high, however, because of uneven amounts of snow under the dense canopy.

[1] A printing, digital integrator provided the average 3-hour temperatures. Air temperature sensors were 1.5 m above ground from May to October and were raised to 3.0 m for the winter.

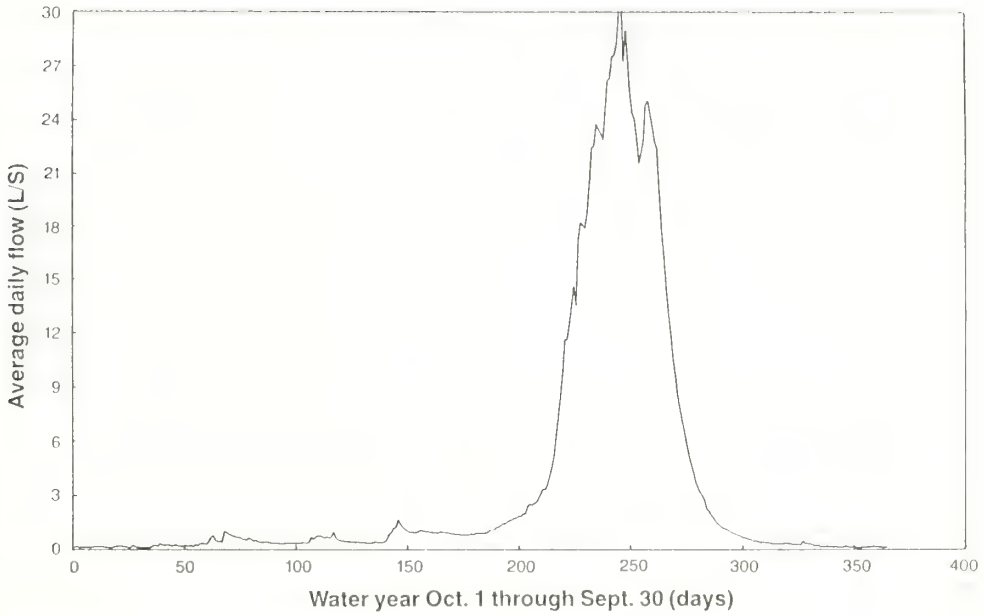

Figure 3--Average daily water yield from watershed 1, 1966-76.

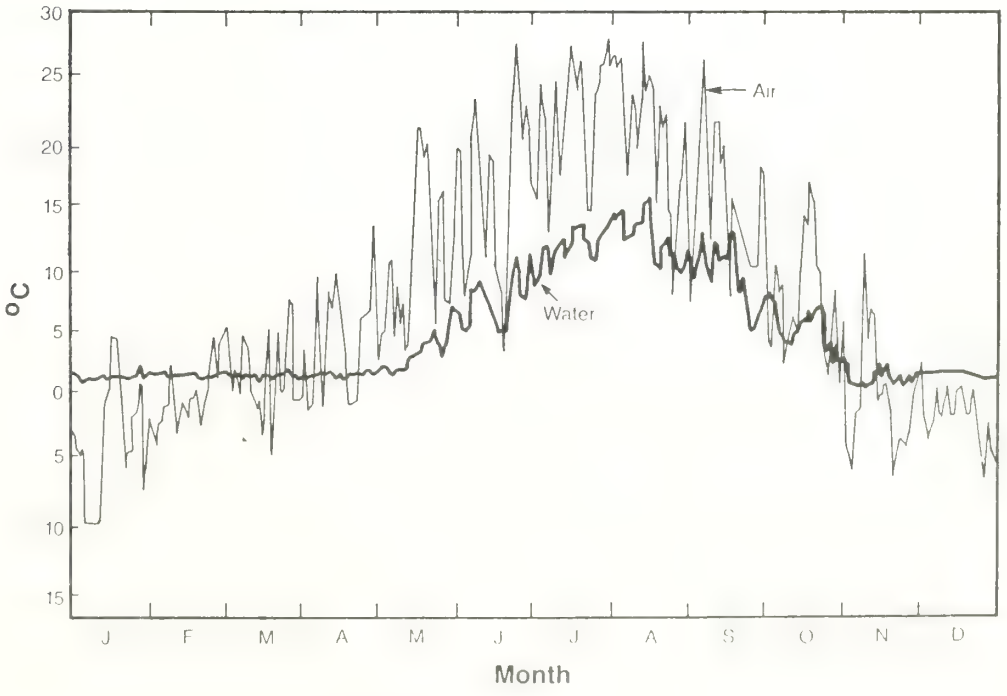

Figure 4--Maximum and minimum of 3-hour average temperatures for air and water temperatures in watershed 4, 1974

Windspeed at 6 m above ground in three watersheds (1, 3, and 4) averaged 0.16 km/h and rarely exceeded 9.6 km/h during the calibration period. Measurements at 20 m above ground were made in watersheds 1 and 4. At 20 m in watershed 1, the measurement was under the taller (up to 40 m) trees, and average windspeed was 0.67 km/h. Trees were shorter in watershed 4, and the measurement at 20 m was at the top of the live crowns; average windspeed was 3.3 km/h. Total wind passage at this location was 23 655 km from August 14, 1975, to July 9, 1976. Wind passage was distributed among the windspeed classes as follows:

Windspeed (km/h)	Total passage (km)
0 – 9.59	18 076
9.60 – 16.09	4 768
16.10 – 24.09	763
24.10 – 31.19	53
31.20 – 48.29	5
48.30 +	0

Watershed Treatments

Table 2 lists the treatments for the four watersheds. Shelterwood cutting and clearcutting were appropriate harvest methods for the forest type and were selected so that their hydrologic and climatic effects could be observed. The main timber-hauling road was built during midsummer 1975. Only watersheds 1 and 4 had roads (see fig. 1). All areas were tractor-logged during July and September 1976; residue treatment and erosion control were completed by October 1976. Seedlings of Engelmann spruce, western larch, and subalpine fir were planted in 1977. Little erosion-control seeding was needed on these moderate slopes; only 4 of the 10 small clearcuts in watershed 4 and one-half of each of the large clearcuts in watershed 1 were seeded (Helvey and Fowler 1979).

Table 2—Watershed treatments

Watershed	Type of cut	Area	Area logged	Stand removed	Volume removed
		Hectares		*Percent*	*Cubic meters*
1	2 large clearcuts; 3.6 ha, 8.5 ha	29.6	12.1	43	2910
2	Shelterwood	24.4	24.4	50	5540
3	None	53.3	0	0	0
4	10 small clearcuts, 0.8 to 2.4 ha	118.1	19.9	22	3690

Results and Discussion

Annual Water Yield

Figure 5, A, B, and C, presents the relations for annual water yield between the control watershed (3) and the treatment watersheds (1, 2, and 4). The solid dots represent water years 1967 to 1976. The calibration equations are shown where X is the control watershed yield and Y is the predicted yield for the treatment watershed. The coefficient of determination (R^2, or the ability of the predictor equation to explain the observed yields) varies between 0.83 and 0.94. For this type of paired comparison, the smaller the scatter of data points, the higher the value of R^2 and the more sensitive the comparisons between pretreatment and posttreatment phases. (For the western Oregon watersheds analyzed by Harr (1982), R^2 values of 0.99 and 0.98 were observed.) A computed 95-percent confidence interval for individual measurements is shown above the regression line. Posttreatment increases must lie beyond this level to be statistically significant at the 95-percent probability level. For watershed 1, increased yields of 17 cm or greater (more than twice the originally predicted response) would be required

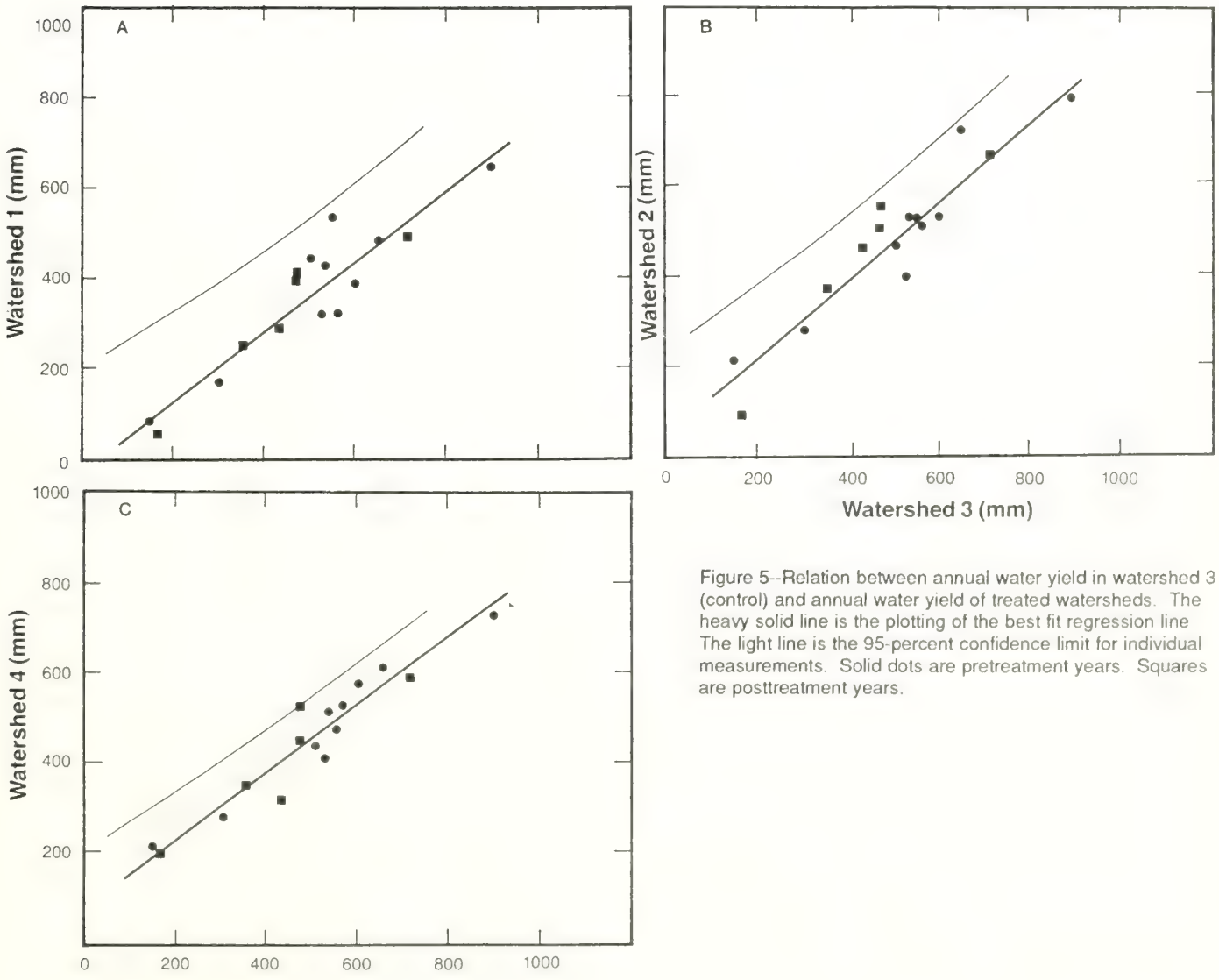

Figure 5--Relation between annual water yield in watershed 3 (control) and annual water yield of treated watersheds. The heavy solid line is the plotting of the best fit regression line The light line is the 95-percent confidence limit for individual measurements. Solid dots are pretreatment years. Squares are posttreatment years.

to satisfy this criterion. Squares represent the posttreatment water years, 1977 to 1982. None of the posttreatment data for all watershed pairs exceed the confidence interval; a null hypothesis of no observed effects due to treatments in these watersheds cannot be rejected.[2]

No significant increases in water yield could be shown in a similar analysis that compared precipitation (the gauge was in watershed 1) and water yield from these watersheds for the pretreatment and posttreatment periods. Felix[3] showed, in an independent analysis, no statistically significant changes in either low or peak flows in the posttreatment period.

Klock and Lopushinsky (1980) found that clearcuts in these same watersheds had about 20 cm more available water in the profile than did corresponding unlogged areas at time of maximum water depletion (August or September). Ross (1971), however, did not find reduced depletion of soil water for all years in clearcuttings at similar elevations on these soils.

Temperature of Air, Water, and Soil

Departure of the maximum and minimum temperatures for air and water in treated watersheds from those in the control watershed during the pretreatment and posttreatment periods are shown in figure 6. A point plotted above the zero line indicates that the treatment is warmer than the control; a point plotted below the line indicates that the treatment is cooler than the control. Before treatment, average maximum and minimum temperatures for air and water in the planned treatment watersheds were within ± 1 °C of the control. Posttreatment changes in average maximum air temperature showed that the treatments were then warmer; minimums were much cooler (2.6 °C) in watershed 4 and somewhat cooler (0.5 °C) in watershed 2.

Except for an increase in the average maximum water temperature in watershed 2, all watersheds showed water temperatures (both average maximums and minimums) to be lower after treatment. It seems reasonable with these north- and northeast-facing watersheds that increased nocturnal cooling after timber removal, an increased snowpack, and possibly a delayed melt affecting stream volume and timing were responsible for the lowered stream temperatures. Maximum soil temperatures during 1976 (pretreatment) were 21 °C at 2.5 cm and 16 °C at 10 cm in watershed 4.[4] Soils at these depths remained isothermal (near 0 °C) from November to early to mid-June. Only the initial response to clearcutting was monitored in watershed 1. Figure 7 presents a

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[2] If harvest year 1976 is excluded from these comparisons, the 552.7-mm annual yield from watershed 2 during 1978, the second year after harvest, exceeded the confidence interval by 9.9 mm.

[3] Unpublished Administrative Report, 1984, "Effects of Timber Harvest on Streamflow Response," by Ernesto N. Felix, U.S. Department of Agriculture, Umatilla National Forest, 2517 S.W. Hailey Avenue, Pendleton, OR 97801.

[4] Litter and vegetative cover in the uncut old-growth forest was essentially 100 percent. Disturbance from the logging was severe. In September 1978, 2 years after harvest, litter and vegetative cover averaged only 62 percent in thirteen 0.4-m^2 plots in the unseeded area in the smaller clearcut in watershed 1. In the seeded section of this clearcutting in 14 plots, total cover averaged 88 percent of the area.

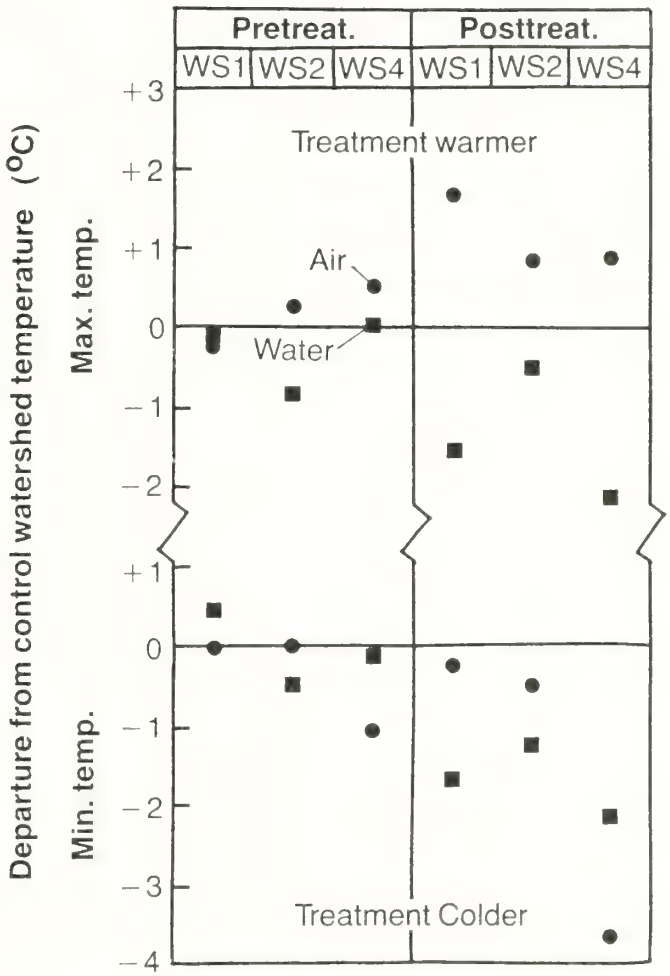

Figure 6--Differences in average maximum and minimum temperatures between control and treated watersheds for pretreatment and posttreatment periods.

14-day record of soil temperatures at 2.5 cm in the logged and unlogged stands. Canopy removal expanded the diurnal range: maximums increased and minimums decreased compared with the unlogged stand.

Wind

Immediate and substantial changes in total wind passage and average windspeeds accompanied removal of the forest stand. Figure 8 presents data from roughly equivalent 11-month periods during pretreatment and posttreatment. Data presented above describing wind passage in various windspeed classes during the pretreatment period at 20 m above ground in watershed 4 are shown as 4(20)A in this figure. Posttreatment wind passage in the six windspeed classes at this location is shown as 4(20)B. Slightly less wind passage is shown in the posttreatment period at the higher windspeeds. As we noted above, only rarely during pretreatment was wind passage at other sites observed at windspeeds of 9.6 to 16 km/h and none at higher windspeeds. Plots 4(6)A, 1(20)A, and 1(6)A show the pretreatment data at 6 m above ground in watershed 4 and at 20 m and 6 m above ground in watershed 1. Plots 4(6)B, 1(20)B and 1(6)B show the posttreatment data. Even at 6 m above ground in the clearcutting in watershed 1, more wind passage in any windspeed class was observed than at 20 m in watershed 4.

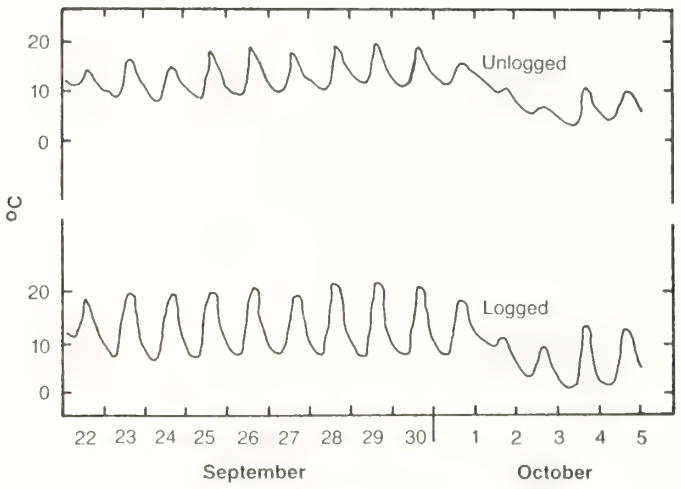

Figure 7--Soil temperature at 0.025 m in logged and unlogged areas, by day.

These dramatic changes in wind passage and windspeed could (1) affect snow distribution within these small watersheds (even to the extent of moving snow beyond watershed boundaries), and (2) change the relative values of evaporation and sublimation from the snowpack and of evaporation from the exposed soil surface that resulted from harvest and residue treatments.[5] Both effects could reduce the relative gains in water yield expected from biomass removal.

Snow Accumulation

Snow accumulation in untreated stands during the pretreatment period was not significantly different among the five measurement plots.[6] During the first winter after harvest, 1976-77, no snow measurements were taken because that winter was one of the driest on record and only patchy snow accumulated. During the 1978 water year, although generally more snow accumulated in openings than in forest stands, a credible measurement of snow water content could not be made at maximum snow accumulation. Numerous ice layers and up to 0.75 m of granular snow and ice at the soil surface gave no structure to the pack.

Snow accumulation and water content were close to average in 1979. An analysis of variance of snow depth and water content measurements taken on March 1, 1979, showed a highly significant difference ($P<0.01$) among plots. The combined average snow depth in treated plots, 220.9 cm, was significantly greater ($P<0.05$) than the average for untreated plots, 182.2 cm. Water content was also significantly greater in treated plots, 68.1 cm, as compared with untreated controls, 57.4 cm.

[5] Soil temperatures were measured only in watersheds 1 and 4.

[6] Two plots in the larger clearcut in watershed 1, one plot in watershed 3 (untreated), and two plots (one treated, one untreated) in watershed 4.

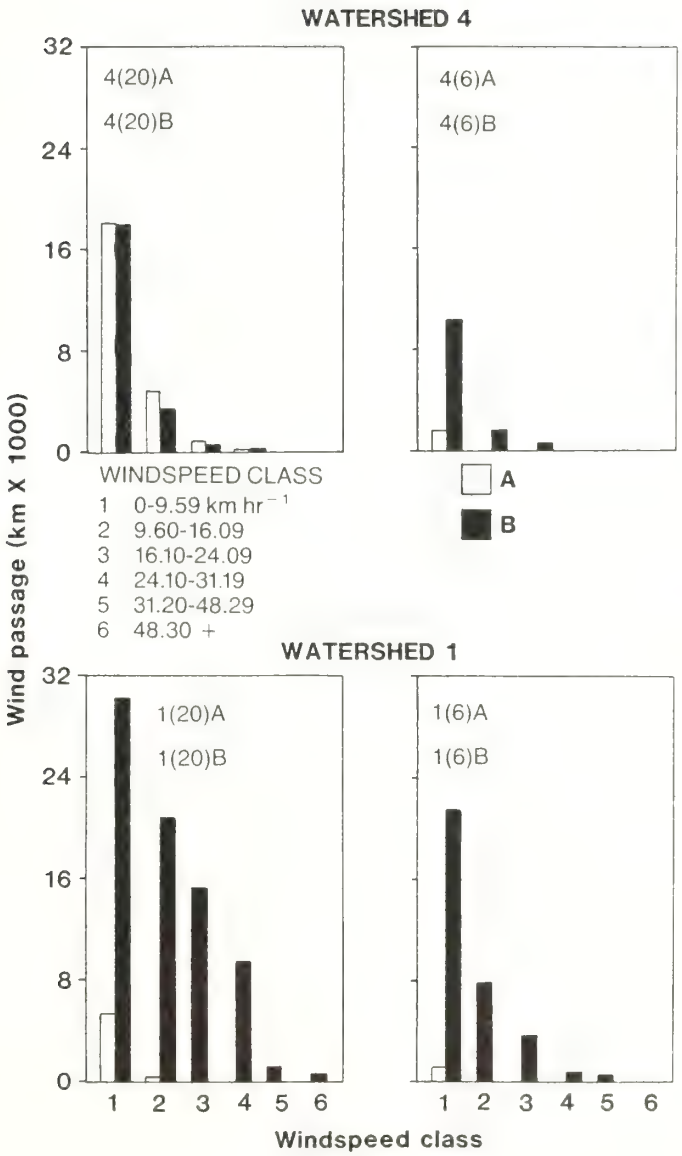

Figure 8--Wind passage in six windspeed classes at 6 and 20 m in watersheds 4 and 1 during two 11-month periods--one before and one after treatment.

Conclusions

Because this study is unreplicated, observations apply only to the study area. In this watershed complex, the hydrology was relatively insensitive to timber harvest. Although an increased soil water content, up to 20 cm, and increased snow water content, up to 11 cm, were observed in clearcut stands, no increase was observed for annual water yield that fell outside the 95-percent confidence intervals established during the calibration period; similarly, no significant response in low or peak flows was observed. Snow redistribution and enhanced evaporation and sublimation could have moderated any yield increase. These watersheds on fractured basalt may be subject to considerable deep seepage, and the control stream was relatively insensitive as compared with treatment streams. With the exception of watershed 2 where timber harvest occurred in

the riparian zone, wide buffer strips adjoined the permanent streams. How effective these forested areas were in capturing any increased intransit flow to the stream channels is also unknown.

More predictable than the water-yield response were the responses of wind and of air and soil temperatures. Dramatic increases in wind passage and windspeeds occurred. Evidence of increased diurnal range in air temperature, especially the lowering of average minimums in the small clearings, may indicate thermal problems for tree regeneration. Additional research is needed on the microclimate of these high-elevation stands and on the dynamics of revegetating plant communities. The USDA Forest Service Forestry Sciences Laboratory at Wenatchee is doing this research.

English Equivalents

To convert:	To:	Multiply by:
Millimeters	Inches	0.03937
Centimeters	Inches	0.3937
Meters	Yards	1.094
Kilometers	Miles	0.6214
Hectares	Acres	2.471
Liters per second	Cubic feet per second	0.03531
Celsius	Fahrenheit	(9/5 °C) + 32
Grams per cubic centimeter	Pounds per cubic feet	62.43
Square meters	Square yards	1.196
Cubic meters	Cubic feet	35.31

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☆U.S. GOVERNMENT PRINTING OFFICE: 1987-795-069/60177

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No significant increases in annual water yield were shown for three small watersheds in northeastern Oregon after shelterwood cutting (30-percent canopy removal, 50-percent basal area removal) and clearcutting. Average maximum air temperature increased after harvest and average minimum air temperature decreased by up to 2.6 °C. Both maximum and minimum water temperatures decreased slightly in two streams as compared with the control stream. Wind passage and velocities increased dramatically with removal of the forest cover. Both snow depth and snowpack water content increased in clearcuttings.

Keywords: Logging effects, hydrologic analysis, climatic change, watershed management, Oregon (Blue Mountains), Blue Mountains—Oregon.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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Research Paper
PNW-RP-380

ARKANSAS' Forest Products Industry: Performance and Contribution to the State's Economy, 1970 to 1980

Con H Schallau, Wilbur R. Maki, Bennett B. Foster, and Clair H. Redmond

Abbreviations

States

AL	Alabama
AR	Arkansas
FL	Florida
GA	Georgia
KY	Kentucky
LA	Louisiana
MS	Mississippi
NC	North Carolina
OK	Oklahoma
SC	South Carolina
TN	Tennessee
TX	Texas
VA	Virginia
SO	South
US	United States

Industries

FPI	Forest Products Industry
LWP	Lumber and Wood Products
PAP	Paper and Allied Products
WF	Wood Furniture

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Abstract

Schallau, Con H; Maki, Wilbur R.; Foster, Bennett B.; Redmond, Clair H. Arkansas' forest products industry: performance and contribution to the State's economy, 1970 to 1980. Res. Pap. PNW-RP-380. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1987.** 22 p.

Accounting for one of every six basic jobs, the forest products industry in Arkansas is the second largest component of the State's economic base. Furthermore, Arkansas is the most timber-dependent State in the South. Between 1970 and 1980, employment increased in the paper and allied products segment but decreased in the wood furniture and the lumber and wood products segments. Arkansas was one of two Southern States that had a smaller share of the Nation's employment in the forest products industry in 1980 than in 1970. This trend resulted partially from a shakeout of the southern pine plywood industry.

Keywords: Forest products industries, economics (forest products industries), employment (forest products industries), Arkansas.

Preface

This report briefly describes Arkansas' forest products industry—its composition, location, evolution, and relation to economic activity elsewhere in the State, the South, and the Nation.

Estimates of employment and earnings shown in this report were derived from U.S. Department of Commerce data. All references to dollar amounts are in constant 1977 dollars.

This is one in a series of reports for each of the 13 Southern States. These reports are companions to an analysis of the interregional competition in the forest products industries of the South and the Pacific Northwest.

Highlights

- Arkansas is the most timber-dependent State in the South. The forest products industry, which accounts for one of every six basic jobs, is the second largest component of Arkansas' economic base.

- Despite modest growth in employment, value added by the forest products industry increased substantially between 1972 and 1977.

- Value added increased by 17 percent; paper and allied products experienced the most growth and wood furniture the least.

- The paper and allied products segment had the highest productivity in Arkansas' forest products industry. Productivity per worker hour was almost 50 percent greater than the average for the State's forest products industry. The lumber and wood products segment experienced the largest gain in productivity between 1972 and 1977.

- The forest products industry is, in general, more important in the southern half of the State than elsewhere. In the southern half, the forest products industry grew in importance between 1970 and 1980, unlike the situation in the rest of the State.

- Between 1970 and 1980, employment in the forest products industry increased in every Southern State except Arkansas and Louisiana. Moreover, the Southern States also increased their share of the Nation's employment in the forest products industry, and all but Louisiana increased their share of earnings.

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1 **The Forest Products Economy of Arkansas**
1 The State's Work Force
2 Components of the State's Economic Base
4 Geographical Importance of the State's Forest Products Industry
5 Composition of the State's Forest Products Industry
6 Average Annual Earnings per Worker
7 Value Added by the Forest Products Industry
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The Forest Products Economy of Arkansas

The State's Work Force

Arkansas' estimated full- and part-time work force in 1980 was comprised of about 981,000 employees and proprietors (see appendix 1, table 1, for sources of employment and earnings data). Arkansas' work force grew significantly faster between 1970 and 1980 than did the national average (27.3 versus 22.3 percent). Total earnings—wage and salary payments and proprietorial income—grew much faster than the national average. Measured in constant 1977 dollars, the State's earnings increased by 44.6 percent compared with 27.4 percent for the Nation. As can be seen in the following tabulation, manufacturing, services, retail trade, and State and local government were the State's four largest employer categories:

	Percent of total employment, 1980	
Employers	**Arkansas**	**U.S.**
Major industries:		
Manufacturing (including forest products industry[1/])	21.3	19.2
Services	14.5	18.2
Retail trade	12.3	14.2
State and local government	12.1	12.6
Agriculture	10.6	4.4
Self-employed	8.6	6.6
Transportation, communication, and public utilities	4.4	4.8
Wholesale trade	4.0	5.0
Construction	3.8	4.1
Finance, insurance, and real estate	3.2	5.0
Federal military	2.4	2.8
Federal civilian	2.1	2.8
Mining	.5	1.0
Total[2/]	100.0	100.0

[1/] The forest products industry is comprised of (1) lumber and wood products (SIC 24), except mobile homes (SIC 2451); (2) wood furniture manufacturing (SIC 2511, 2512, 2517, 2521, 2541); and (3) paper and allied products (SIC 26).

[2/] Sum of parts may not equal totals because of rounding.

Components of the State's Economic Base

Along with total employment there is another and perhaps more important way to judge an industry's contribution to Arkansas' economy. For the State's economy to grow and develop, it must attract new dollars so residents can buy goods and services produced elsewhere. The industries that export products and services beyond local boundaries (that is, to elsewhere in the State, to other States, and to the world) and bring in new dollars, constitute the areas' economic base. Generally speaking, most manufacturing employment is classified as "economic base" (or "basic"); service or residentiary employment (for example, barber shops, realty firms, schools, and local government) is geared primarily to producing for local needs. Some services may, however, be basic. Furthermore, a particular industry may qualify as basic at the local level but not at the State level. Federal military, therefore, qualifies as a basic industry.

Residentiary employment is supported by the economic base. Money flowing in provides income for wage earners and entrepreneurs to spend on locally purchased goods and services. In most cases, the economic growth of a region is dependent on the success of its economic base.

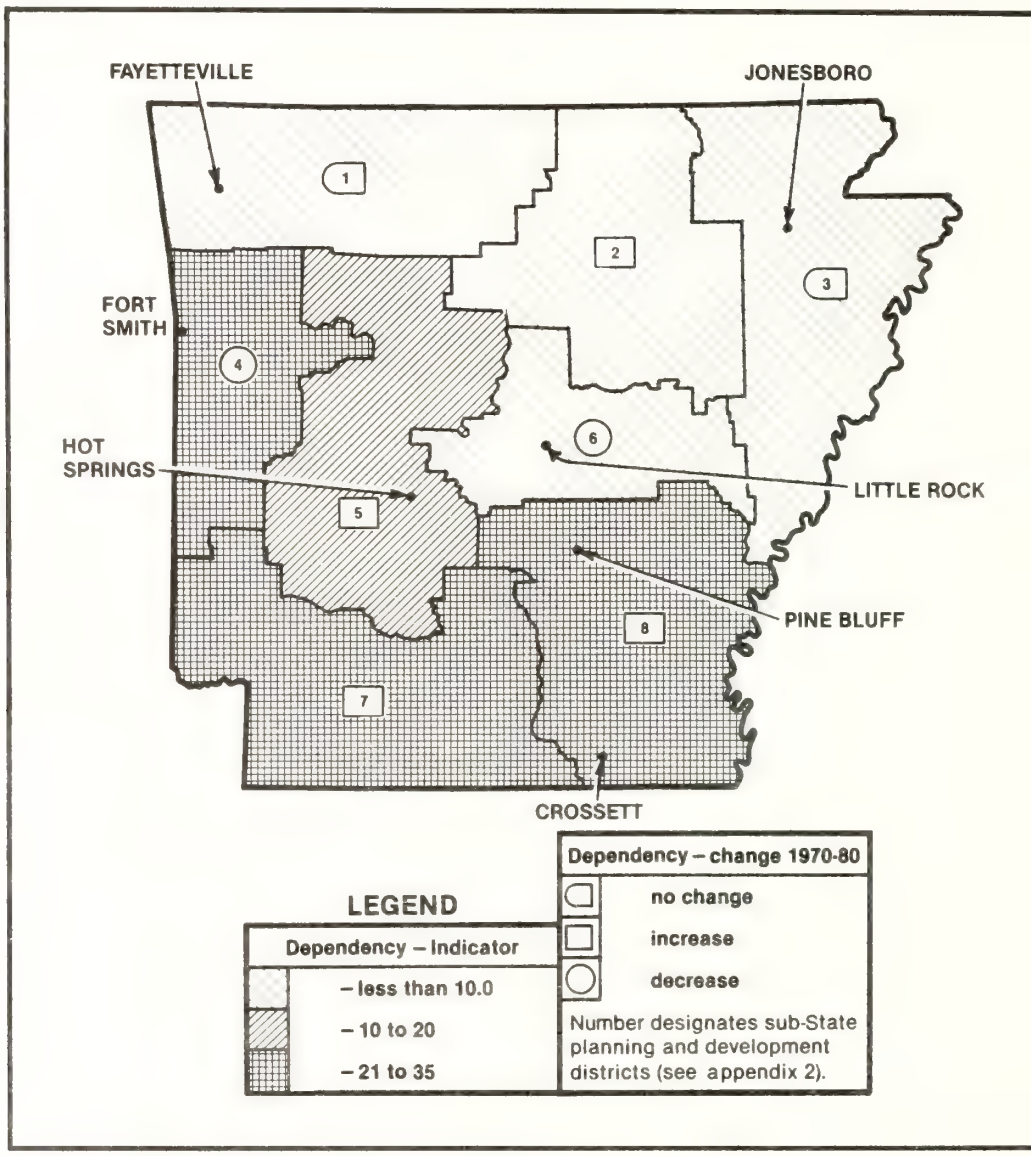
We used the excess employment technique to identify the industries that comprise Arkansas' (or sub-State district's) economic base. This approach accepts the national distribution of employment among industries as a norm. Any industry with employment in excess of this norm is considered to be producing for export markets outside the State (or sub-State district) and is part of Arkansas' economic base. The percentage of Arkansas' excess employment served as an indicator of the State's dependency on a particular industry for generating new dollars from outside the State (table 2 shows how excess employment and industry dependency indicators for Arkansas were calculated).

In 1980, seven industries accounted for 91.4 percent of the State's excess employment—that is, its economic base (see tabulation below). Although these same industries accounted for about the same share (93.3 percent) in 1970, the change in shares of certain individual industries is noteworthy. In 1970, agriculture and food and kindred products accounted for about 60 percent of the State's basic employment. By 1980, they accounted for only 53 percent. Meanwhile, the combination of the forest products industry and the self-employed components of the economic base increased in importance. Many in the self-employed component are involved in logging, hauling, and other forest products industry activities.

Economic base industries	Dependency indicator	
	1970	1980
	(Percent of economic base)	
Agriculture	54.0	42.0
Forest products	17.0	16.6
Self-employed	10.4	13.6
Food and kindred products	6.7	11.5
Leather and leather products	3.8	3.5
Electrical machinery	.1	2.6
Railroad transportation	1.3	1.6
Subtotal	93.3	91.4
All other industries	6.7	8.6
Total	100.0	100.0

Geographical Importance of the State's Forest Products Industry

The contribution of the forest products industry to Arkansas' economic base varies considerably among sub-State districts (see appendix 2 for a listing of counties by district). The industry is least important in the northwestern and northeastern districts. The two southern-most districts were not only more timber dependent than most of the remainder of the State, but also were more timber dependent in 1980 than in 1970.



Source: Sub-State estimates for 1970 and 1980 were derived from unpublished county data series provided by the U.S. Department of Commerce, Regional Economic Information System, Washington, DC, and from the Department's *County Business Patterns*. The numbers designate sub-State districts corresponding to the geographical classification of counties as shown in appendix 2.

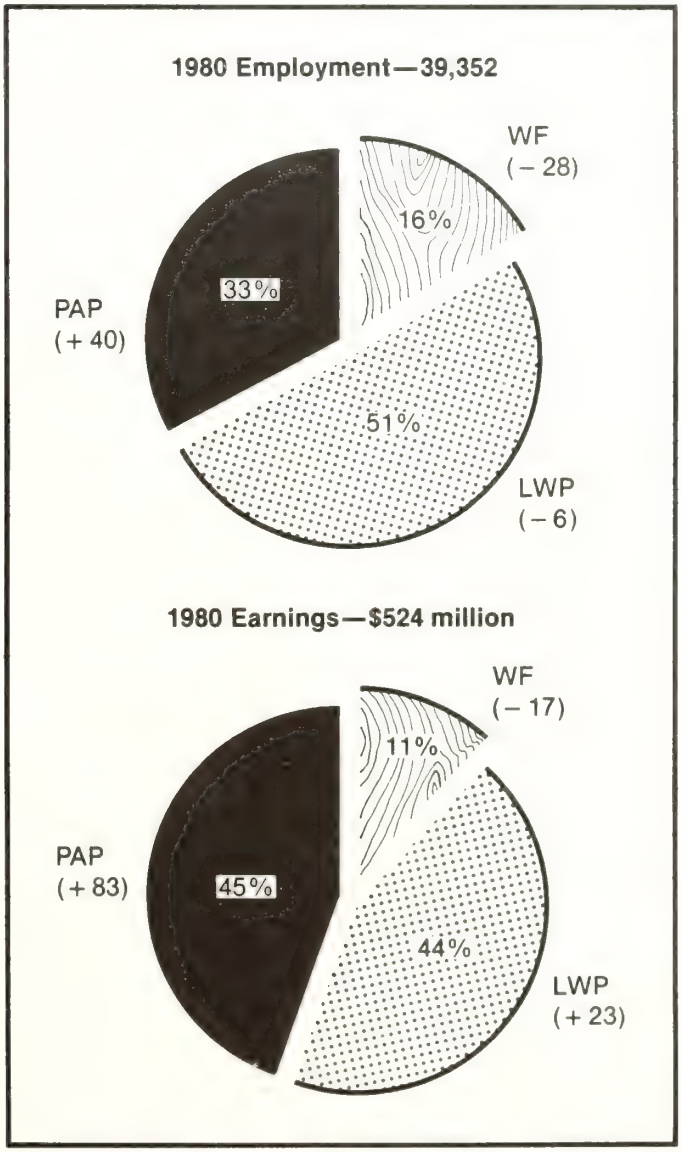
Composition of the State's Forest Products Industry

Arkansas' forest products industry is comprised of paper and allied products, lumber and wood products (not including mobile homes), and wood furniture manufacturing. Employment decreased in two of the three segments between 1970 and 1980. This decrease reflects, in part, the closure of older, more labor-intensive sawmills and a shakeout in the southern pine plywood industry.[3/]

In 1980, lumber and wood products accounted for the largest share of about 39,000 workers employed by Arkansas' forest products industry. The share of 1980 earnings for paper and allied products was slightly larger than that for lumber and wood products.

While employment increased appreciably in paper and allied products between 1970 and 1980, it decreased in the other two segments of the industry. Earnings in the paper and allied products segment came close to doubling during the 1970's. Meanwhile, lumber and wood products increased by nearly 25 percent.

[3/]Shakeout is one of five fundamental stages of product-market evolution: development, growth, shakeout, maturity-saturation, and decline. See David A. Cleaves and Jay O'Laughlin. 1985. "Forest inventory, plant location and company strategies." In: Proceedings of the 1985 Southern Forest Economic Workers (SOFEW) workshop; 1985 March 13-15; Athens, GA. Athens GA: University of Georgia; p. 35-43.

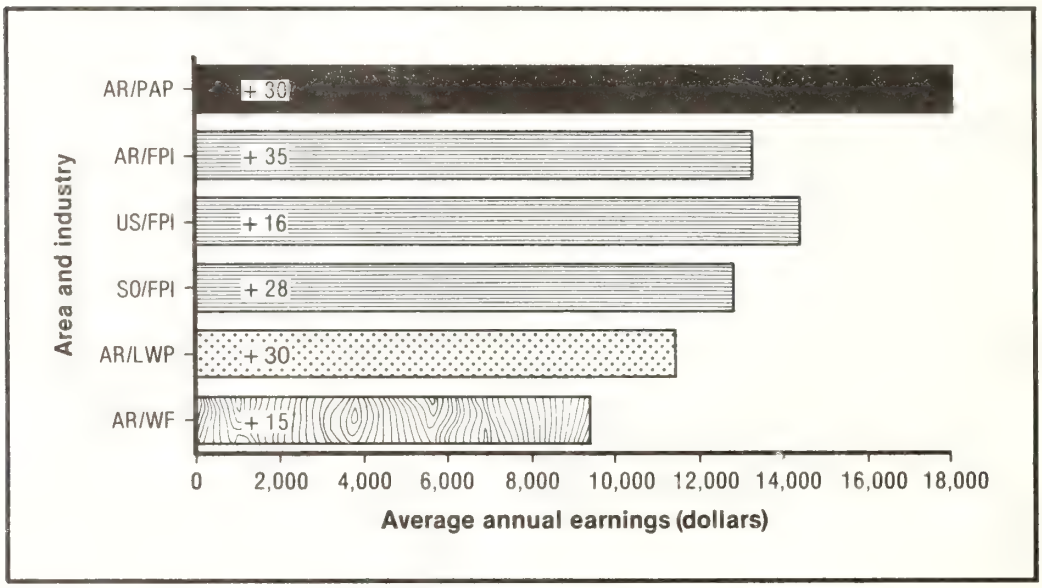


Numbers in parentheses show percentage of change from 1970 to 1980.

Average Annual Earnings per Worker

Average annual 1980 earnings per worker in the paper and allied products segment were greater than were earnings in the other two segments of the forest products industry. Higher average skill levels, capital investment per worker, and unions account for this difference. Earnings in the wood furniture industry were more than half of those for paper and allied products and were significantly below the average for all forest products industries in the South and the United States.

The rate of growth in earnings was greater for Arkansas' forest products industry than for the South and the Nation. The difference resulted from the growth in earnings of both the paper and allied products and lumber and wood products segments. The rate of change for wood furniture was less than that of the United States and less than that of the forest products industry in the South.

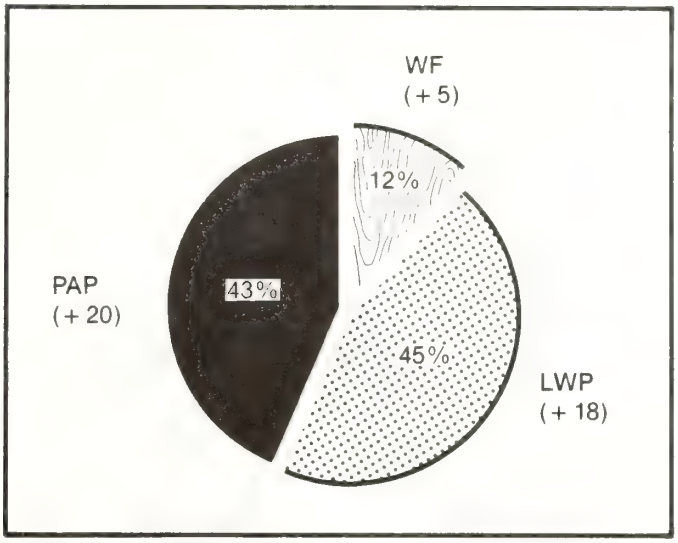


Numbers in bars show percentage of change from 1970 to 1980.

Value Added by the Forest Products Industry

Value added by manufacturing represents income payments made directly to workers and business owners. It is equal to the value of shipments less the cost of materials, parts, supplies, fuel, goods purchased for resale, electric energy, and contract work. Unlike value of shipments, value added includes only the economic contributions of the State's forest products industry. Consequently, value added by manufacturing is considered a better monetary gauge of the relative economic importance of a manufacturing industry. In 1977, lumber and wood products had the largest share of the $940 million of value added by Arkansas' forest products industry.

Despite modest growth in employment, value added by the forest products industry increased substantially between 1972 and 1977. Value added increased by 17 percent; paper and allied products experienced the most growth and wood furniture the least.



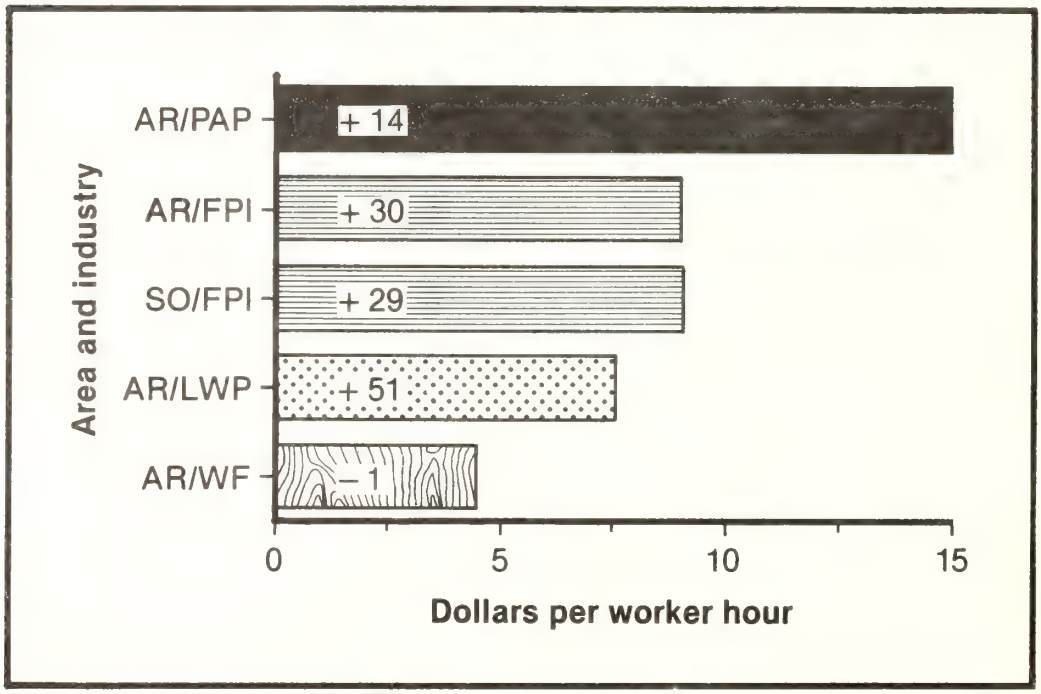
Numbers in parentheses show percentage of change from 1972 to 1977.

Capital Productivity

Increases in productivity are necessary for an industry to remain competitive in the marketplace. The productivity of capital of an industry is measured in terms of value added minus payrolls per worker hour—VAMP (see table 3 for an explanation of how productivity was calculated for Arkansas' forest products industry). This measure of productivity represents profits before taxes and adjusts for wide differences in payrolls among industries.

Paper and allied products had by far the highest productivity in Arkansas' forest products industry. Productivity per worker hour in this segment was almost 50 percent greater than the average for the State's forest products industry.

The lumber and wood products segment experienced the largest gain in productivity between 1972 and 1977. Paper and allied products is more capital intensive and in the past has attracted considerable investment in new facilities and equipment. As a consequence, its productivity increased despite increased labor costs. During the mid-1970's, however, this segment exhibited a smaller gain in productivity than the average for the forest products industry in the South.



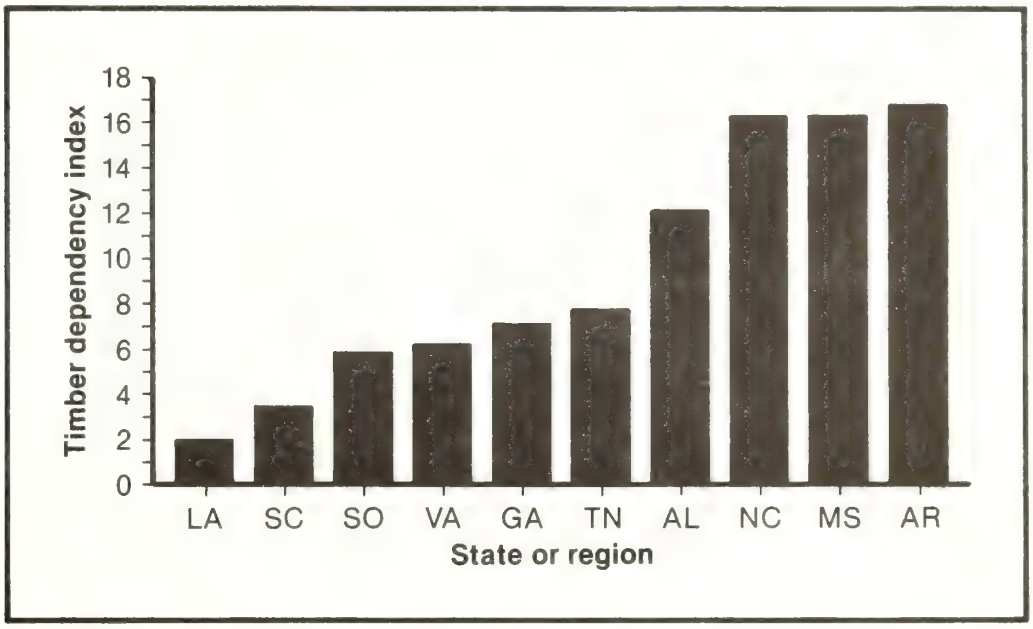
Numbers in bars show percentage of change from 1972 to 1977.

The Forest Products Industry in the South

Importance of the Industry Across the South

The dependency indicators suggest that in 1980 all but four States in the South manufactured forest products in excess of statewide needs. Agriculture continues to dominate Arkansas' basic economy; nevertheless, Arkansas was the most timber-dependent State in the South.

Florida, Kentucky, Oklahoma, and Texas were not self-sufficient with respect to forest products; that is, these States imported more forest products than they exported. Consequently, on net balance, their respective forest products industries did not generate new dollars from the outside. In three States—Arkansas, Mississippi, and North Carolina —the forest products industry accounted for about one of six basic employees.



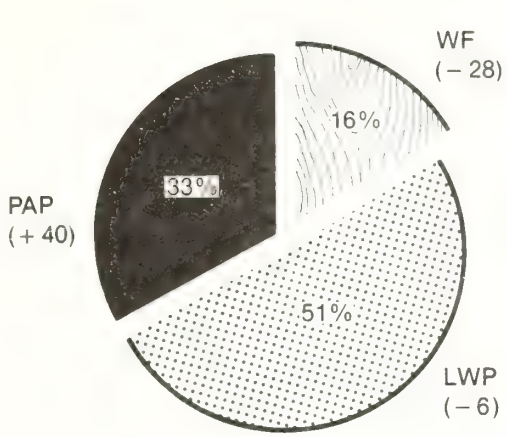
Industry Composition

Both the paper and allied products and lumber and wood products segments accounted for larger shares of 1980 employment and earnings in Arkansas' forest products industry than they did for the South. Employment in the lumber and wood products segment decreased in Arkansas during the 1970's, unlike employment in that segment in most Southern States.

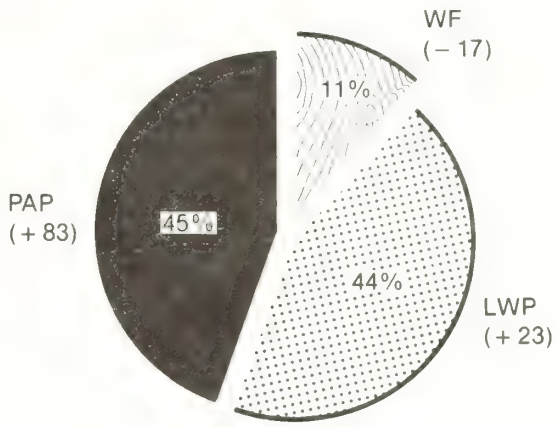
Wood furniture is much less prominent in Arkansas than in the South in general; furthermore, earnings and employment declined during the 1970's. Meanwhile, employment and earnings in the lumber and wood products segment accounted for a larger share of the forest products industry in Arkansas than they did at the national level.

ARKANSAS

1980 Employment—39,352

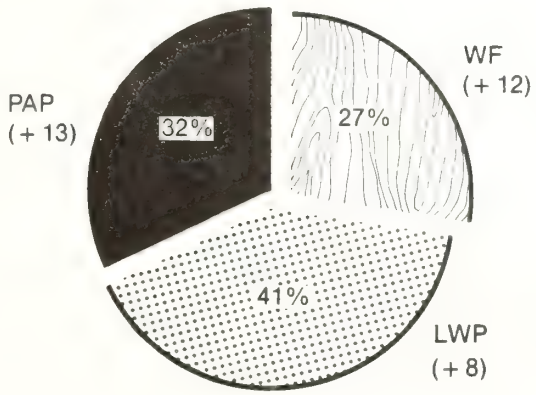


1980 Earnings—$524 million

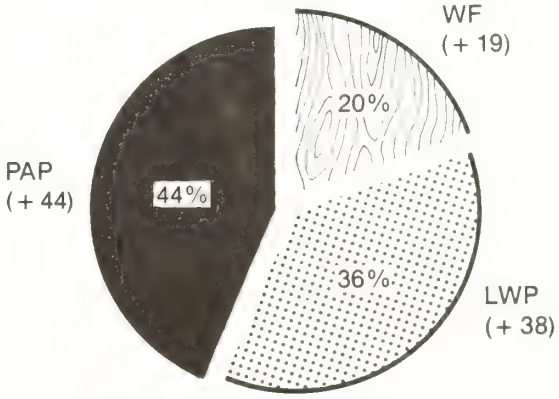


THE SOUTH

1980 Employment—620,567

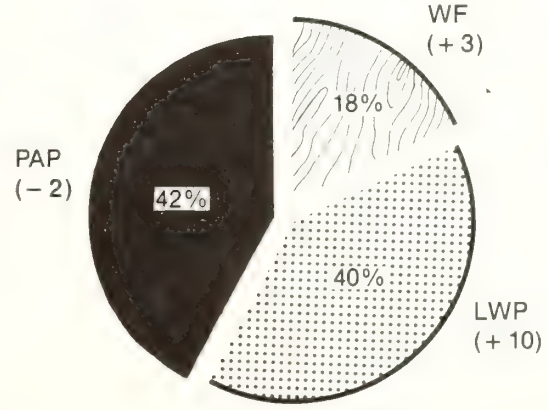


1980 Earnings—$7.96 billion

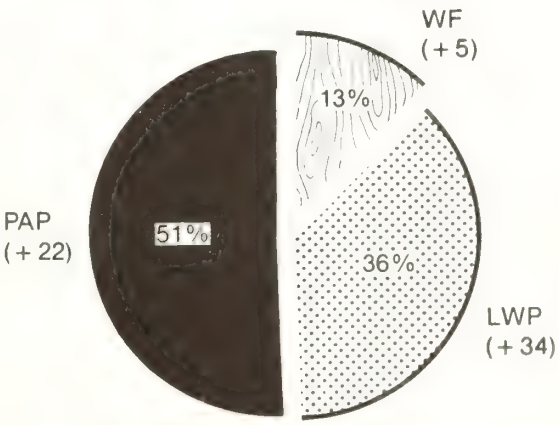


UNITED STATES

1980 Employment—1,634,000



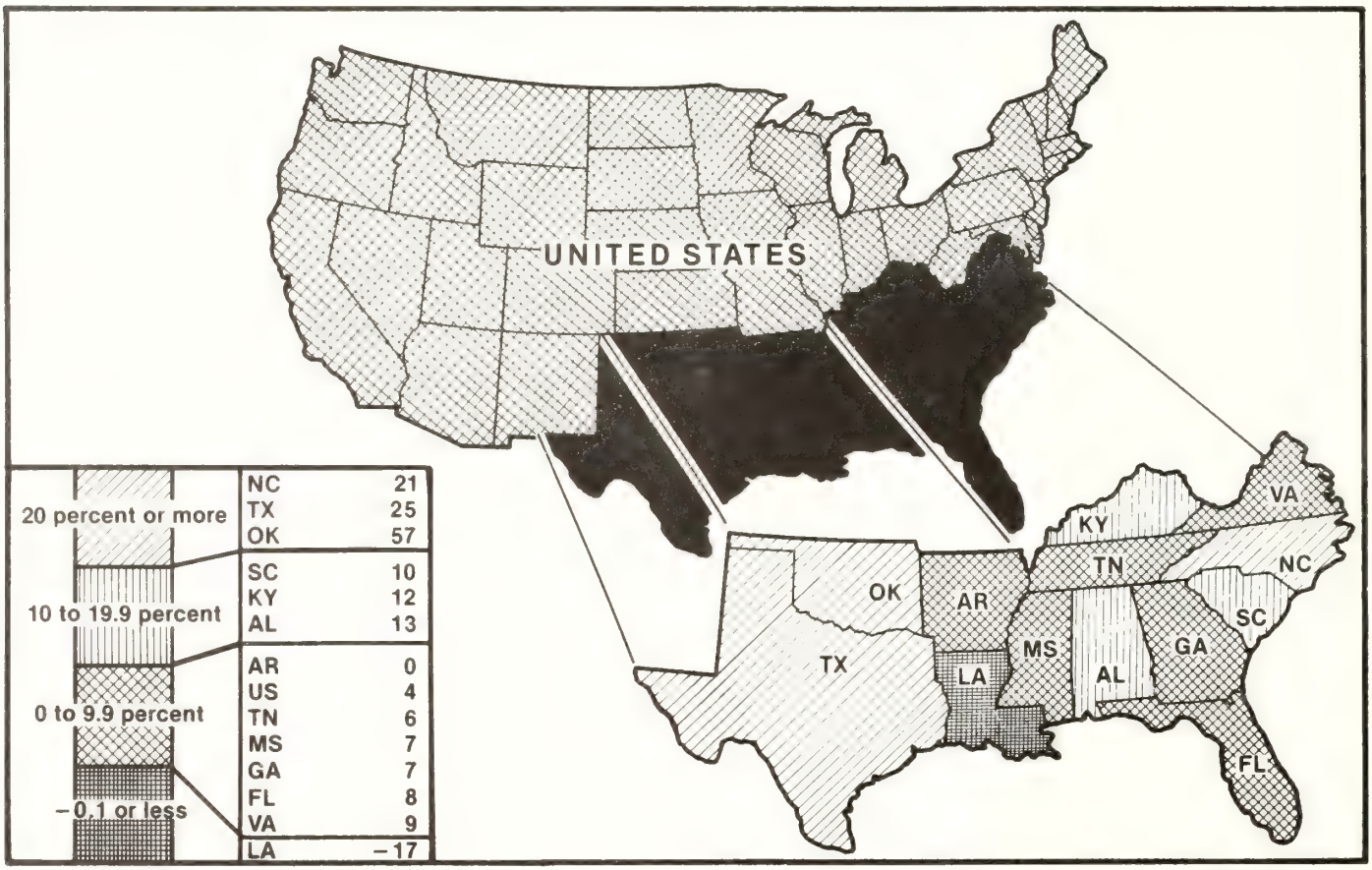
1980 Earnings—$23.65 billion



Numbers in parentheses show percentage of change from 1970 to 1980.

Growth of Employment

Employment in the forest products industry in each of the Southern States, except Arkansas and Louisiana, grew faster between 1970 and 1980 than did the U.S. counterpart. Employment in two States—Oklahoma and Texas—grew faster than the all-industry average of 22.3 percent.

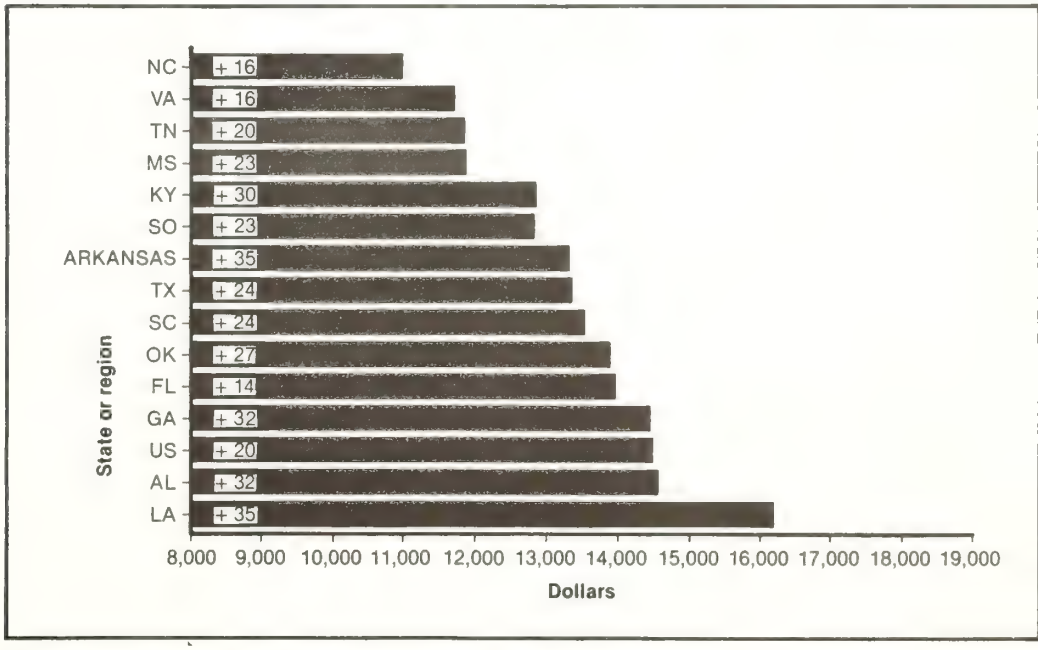


Average Annual Earnings

Average annual earnings per worker in the forest products industry differed significantly by State in 1980: about $5,000 separated the State with the highest (Louisiana) from the State with the lowest (North Carolina). Pulp and allied products manufacturing, which has traditionally paid higher wages than have other segments of the forest products industry, dominated Louisiana's forest products industry. Wood furniture, which has paid lower wages, dominated North Carolina's industry.

Average annual earnings in the forest products industry in Arkansas were slightly above the average for all States in the South but below the average for the United States. Furthermore, earnings increased much faster in Arkansas than in either the South or the Nation.

In general, paper and allied products dominated the forest products industry in the States with the highest average annual earnings. This relation reflects a higher level of job skills and unions in pulp and paper manufacturing. Wages, by and large, were the lowest in States where the labor-intensive wood furniture industry was more important.



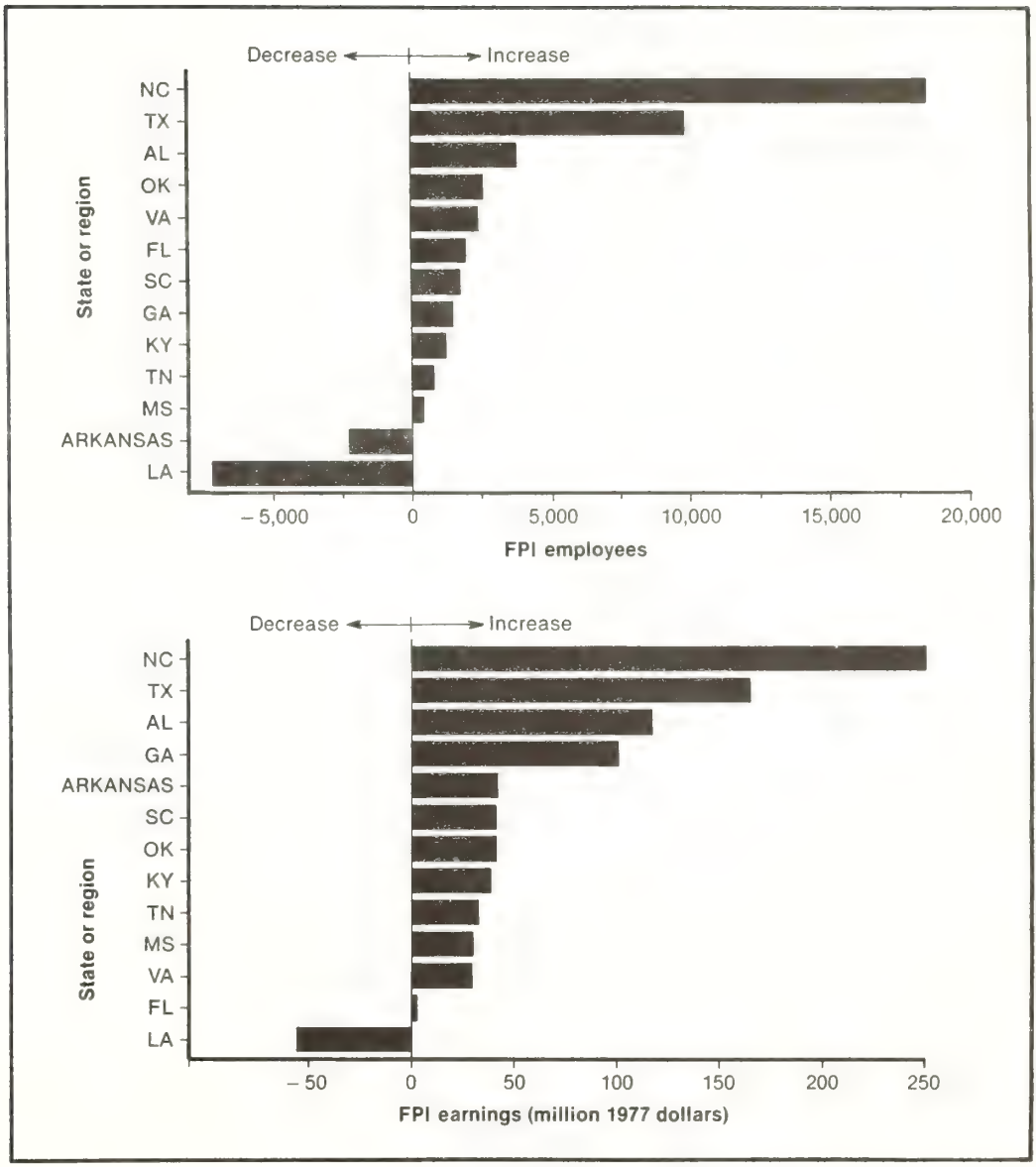
Numbers in bars show percentage of change from 1970 to 1980.

Shift in Employment and Earnings

The regional shift shows how much more or less employment and earnings a State would have had in the forest products industry in 1980 had it grown at the national rate. For example, Arkansas had about 2,300 fewer employees in 1980 than it would have had if its forest products industry had grown at the national rate.

Between 1970 and 1980, total employment in the forest products industry in the United States remained constant but increased in every Southern State except Louisiana. All but Arkansas and Louisiana increased their share of the Nation's forest products industry employment, and all but Louisiana increased their share of earnings.

Increased shares of employment and earnings reflect the comparative advantage the South's forest products industry enjoyed over this industry in the rest of the Nation. Several factors (for example, relatively lower labor costs, lower raw materials costs, and closer proximity to markets) might account for a region's comparative advantage, although adverse trends in one factor need not reduce a region's advantage. In the South, for instance, increasing labor costs need not adversely affect the regions comparative advantage if increased capital or labor productivity offsets higher labor costs.


Decrease
Increase
State or region
NC
TX
AL
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SC
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KY
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MS
ARKANSAS
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– 5,000
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10,000
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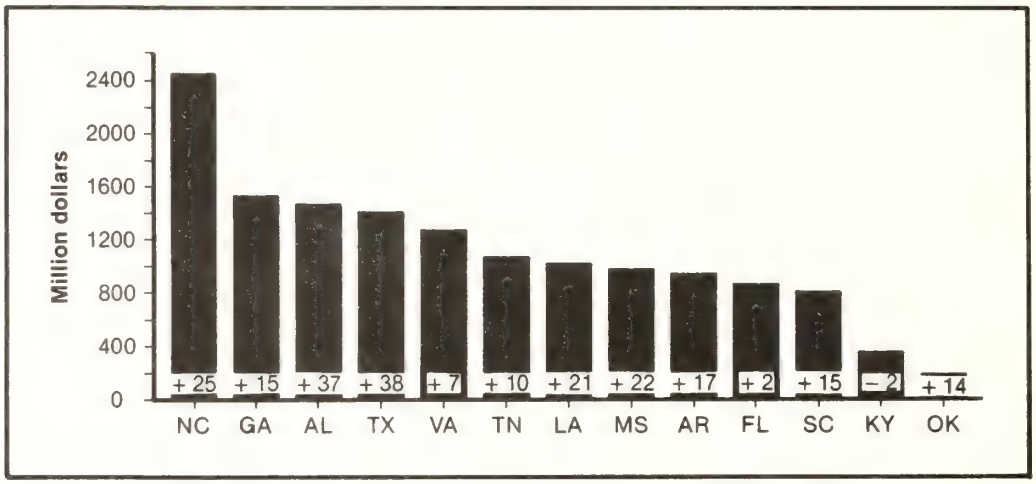
20,000
FPI employees
Decrease
Increase
State or region
NC
TX
AL
GA
ARKANSAS
SC
OK
KY
TN
MS
VA
FL
LA
– 50
0
50
100
150
200
250
FPI earnings (million 1977 dollars)

Value Added by the Forest Products Industry

In 1977, the forest products industry of North Carolina produced more value added than any other State in the South. Georgia was second among the 13 Southern States, and Arkansas was ninth. Texas was not only one of the leading States in terms of total value added, but also led the South in the change in value added between 1972 and 1977. In Arkansas, the change in value added was less than the average rate for the region (19 percent). One State, Kentucky, produced less value added in 1977 than in 1972.



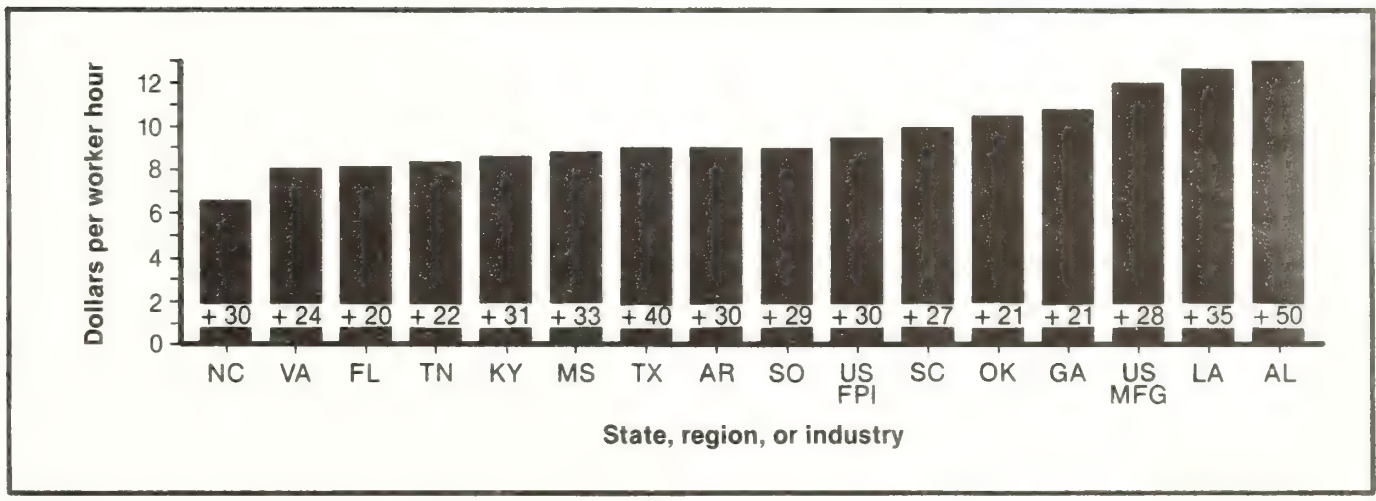
Numbers in bars show percentage of change from 1972 to 1977.

Capital Productivity

The paper and allied products segment, which is more capital-intensive and, therefore, more susceptible to technological change than are other segments of the forest products industry, exhibited the highest productivity within the forest products industry. Wood furniture, on the other hand, is the most labor-intensive of the three. North Carolina, for example, produced more value added than any other State in the South, but the productivity of its forest products industry in 1977 was the lowest. This reflects the dominant role of labor-intensive wood furniture manufacturing in North Carolina.

Increases in productivity exceeded increases in payroll per worker between 1972 and 1977 for all the Southern States. This relation is, in part, responsible for the South's comparative advantage in the forest products industry.

In 1977, productivity of Arkansas' forest products industry was equal to the average for the 13 Southern States. Between 1972 and 1977, productivity increased by 30 percent. This increase, which tied for sixth highest in the South, was achieved despite Arkansas' average annual wages being higher than the average for the region.



Numbers in bars show percentage of change from 1972 to 1977.

Acknowledgment

Many helpful suggestions of several reviewers were incorporated in this research report. The project was funded in part by USDA Forest Service, Resource Program and Assessment Staff, and State and Private Forestry, Area Planning and Development, State Planning for Forest Resources.

Appendix 1
Tables

Table 1—Total labor and proprietorial employment and income, by industry, Arkansas, 1980[1/]

Industry number	Industry	Employees	Total income
		Number	*Thousand 1977 dollars[2/]*
Wage and salary			
1	Agriculture	29,489	632,453
2	Agricultural services, forestry, and fisheries	4,888	45,883
3	Coal mining	134	2,976
4	Oil and gas extraction	3,215	72,515
5	Metal mining	478	8,451
6	Nonmetallic minerals	1,330	17,856
7	Construction	37,546	562,182
8	Food and kindred products	32,565	329,705
9	Tobacco	0	0
10	Textile mill products	3,923	40,624
11	Apparel and other textiles	13,453	92,753
12	Paper and allied products	12,920	233,719
13	Printing and publishing	9,141	94,159
14	Chemical and allied products	7,569	138,668
15	Petroleum refining	1,591	31,864
16	Rubber and miscellaneous plastics	7,882	101,270
17	Leather and leather products	7,324	55,318
18	Lumber and wood products, except mobile homes	19,930	228,419
19	Mobile homes	587	6,728
20	Wood furniture	6,502	61,381
21	Other furniture and fixtures	3,328	31,417
22	Stone, clay, and glass products	5,011	64,683
23	Primary metals	7,847	130,366
24	Fabricated metals	13,373	170,261
25	Machinery, excluding electrical	13,657	167,288
26	Electrical machinery	23,240	277,424
27	Transportation equipment, except motor vehicles	4,035	54,196
28	Motor vehicles	3,194	41,159
29	Ordnance	[3/]—	[3/]—
30	Instruments and related equipment	7,991	79,903
31	Miscellaneous manufacturing	4,154	40,414
32	Railroad transportation	7,209	147,330
33	Trucking and warehousing	13,768	216,495
34	Local transit	958	9,812
35	Air transportation	1,009	14,420

See footnotes at end of table.

Table 1—Total labor and proprietorial employment and income, by industry, Arkansas, 1980[1/] (continued)

Industry number	Industry	Employees	Total income
		Number	*Thousand 1977 dollars[2/]*
Wage and salary			
36	Pipeline transportation	319	6,227
37	Transportation services	461	12,788
38	Water transportation	307	4,551
39	Communications	10,719	188,021
40	Electrical, gas, and sanitation services	8,958	147,016
41	Wholesale trade	39,726	529,792
42	Retail trade	120,419	959,864
43	Banking	11,815	127,668
44	Other credit agencies	4,311	70,981
45	Insurance	8,526	138,495
46	Real estate and combinations	6,424	85,498
47	Hotel and other lodging	7,868	46,455
48	Personal, miscellaneous business, and repair services	21,070	215,057
49	Auto repair service	4,150	62,885
50	Amusement	4,521	27,554
51	Motion pictures	850	3,713
52	Private households	23,106	51,876
53	Medical and other health	43,287	536,131
54	Private education	4,247	32,579
55	Nonprofit organizations	26,496	146,131
56	Miscellaneous services	6,933	176,860
57	Federal civilian	20,863	298,621
58	Federal military	23,635	132,041
59	State and local government	118,832	978,773
Proprietorial			
60	Farm proprietors	69,920	542,736
61	Nonfarm proprietors	84,274	765,877
	Total	981,278	10,493,992

1/Source of data for this table for Arkansas, other States of the South, and the United States: unpublished data, U.S. Department of Commerce, Regional Economics Measurements Division, Regional Economic Information System (REIS), Washington, DC, 1982. Unpublished data used by the U.S. Department of Commerce in preparing their *County Business Patterns* (CBP) series on employment and payroll were used to differentiate wood-related from nonwood-related employment and earnings. For example, CBP data were used to separate mobile homes (no. 19) from the lumber and wood products (no. 18) industry. Wood furniture (no. 20) was similarly separated from other furniture and fixtures (no. 21).

2/The Personal Consumption Expenditure (PCE) deflator, 1977 = 100, was used to deflate nominal dollars.

3/Included with fabricated metals and other related industries.

Table 2—Calculation of 1980 dependency indexes for Arkansas

(In percent)

Industry	Employment		Arkansas excess employment[1]	Dependency index[2]
	Arkansas	United States		
Agriculture	3.51	1.46	2.05	11.72
Agricultural services, forestry, and fisheries	.58	.62	—	—
Farm proprietors	8.33	3.03	5.30	30.28
Coal mining	.02	.27	—	—
Oil and gas extraction	.38	.60	—	—
Metal mining	.06	.11	—	—
Nonmetallic minerals	.16	.14	.02	.12
Construction	4.47	4.74	—	—
Food and kindred products	3.88	1.87	2.01	11.49
Tobacco	—	.07	—	—
Textile mill production	.47	.93	—	—
Apparel and other textiles	1.60	1.39	.22	1.24
Paper and allied products	1.54	.76	.78	4.48
Printing and publishing	1.09	1.37	—	—
Chemical and allied products	.90	1.22	—	—
Petroleum refining	.19	.22	—	—
Rubber and miscellaneous plastics	.94	.80	.14	.82
Leather and leather products	.87	.26	.61	3.50
Lumber and wood products, except mobile homes	2.37	.71	1.67	9.52
Mobile homes	.07	.05	.02	.11
Wood furniture	.77	.32	.45	2.58
Other furniture and fixtures	.40	.19	.21	1.19
Stone, clay, and glass products	.60	.73	—	—
Primary metals	.93	1.26	—	—
Fabricated metals	1.59	1.77	—	—
Machinery, excluding electrical	1.63	2.73	—	—
Electrical machinery	2.77	2.31	.46	2.61
Transportation equipment, except motor vehicles	.48	1.21	—	—
Motor vehicles	.38	.87	—	—
Instruments and related equipment	.95	.77	.18	1.02
Miscellaneous manufacturing	.49	.47	.03	.17
Railroad transportation	.86	.58	.27	1.57
Trucking and warehousing	1.64	1.40	.24	1.37
Local transit	.11	.29	—	—
Air transportation	.12	.50	—	—
Pipeline transportation	.04	.02	.02	.09
Transportation services	.05	.22	—	—
Water transportation	.04	.23	—	—
Communications	1.28	1.48	—	—
Electrical, gas, and sanitation services	1.07	.90	.16	.94
Wholesale trade	4.73	5.79	—	—
Retail trade	14.35	16.50	—	—
Banking	1.41	1.72	—	—
Other credit agencies	.51	.99	—	—

See footnotes at end of table.

Table 2—Calculation of 1980 dependency indexes for Arkansas (continued)

(In percent)

Industry	Employment		Arkansas excess employment[1]	Dependency index[2]
	Arkansas	United States		
Insurance	1.02	1.89	—	—
Real estate and combinations	.77	1.16	—	—
Hotel and other lodging	.94	1.20	—	—
Personal, miscellaneous business, and repair services	2.51	4.69	—	—
Auto repair service	.49	.63	—	—
Amusement	.54	.84	—	—
Motion pictures	.10	.24	—	—
Medical and other health	5.16	5.71	—	—
Private education	.51	1.47	—	—
Nonprofit organizations	3.16	3.01	.15	.83
Miscellaneous services	.83	1.63	—	—
Federal civilian	2.49	3.27	—	—
Federal military	2.82	2.68	.14	.77
Nonfarm proprietors	10.04	7.66	2.38	13.59
Total[3]	100.00	100.00	17.51	100.00

[1]/Arkansas employment minus U.S. employment. Figures may not be exactly equal to Arkansas minus U.S. because of rounding. Dashes signify no excess employment.

[2]/Individual industry excess employment expressed as a percentage of Arkansas' total excess employment (sum of column 4).

[3]/Sum of parts may not equal totals because of rounding.

Table 3—Value added, hours worked, payroll, and capital productivity,[1] Arkansas forest products industry, 1977[2]

Industry	Value added	Payroll	Hours worked	Productivity	Productivity change, 1972-77
	---- *$Million* ----		*Million*	*$VAMP per hour*	*Percent*
Lumber and wood products	422.3	171.3	33.5	7.49	50.87
Wood furniture	108.0	54.0	12.1	4.48	-.56
Paper and allied products	409.7	151.5	17.3	14.92	14.01

[1]/Productivity equals value added minus payroll (VAMP) divided by hours worked. For a discussion of VAMP, see W. Charles Sawyer and Joseph A. Ziegler. 1980. "The use of VAMP shift as a predictive model." Unpublished paper presented at the annual meeting of the Western Regional Science Association, Monterey, California.

[2]/Source: U.S. Bureau of the Census, Census of Manufactures, for 1972 and 1977, Arkansas and the United States, available in 1976 and 1980, respectively. In the few instances where data were not available for some subindustry segments, the distribution of the number of establishments was used to estimate nondisclosures

Appendix 2
Arkansas Counties by Sub-State Planning and Development Districts

District code	Counties
1	Baxter, Benton, Boone, Carroll, Madison, Marion, Newton, Searcy, Washington
2	Cleburne, Fulton, Independence, Izard, Jackson, Sharp, Stone, Van Buren, White, Woodruff
3	Clay, Craighead, Crittenden, Cross, Greene, Lawrence, Lee, Mississippi, Phillips, Poinsett, Randolph, St. Francis
4	Crawford, Franklin, Logan, Polk, Scott, Sebastian
5	Clark, Conway, Garland, Hot Spring, Johnson, Montgomery, Perry, Pike, Pope, Yell
6	Faulkner, Lonoke, Monroe, Prairie, Pulaski, Saline
7	Calhoun, Columbia, Dallas, Hempstead, Howard, Lafayette, Little River, Miller, Nevada, Ouachita, Sevier, Union
8	Arkansas, Ashley, Bradley, Chicot, Cleveland, Desha, Drew, Grant, Jefferson, Lincoln

Schallau, Con H; Maki, Wilbur R.; Foster, Bennett B.; Redmond, Clair H. Arkansas' forest products industry: performance and contribution to the State's economy, 1970 to 1980. Res. Pap. PNW-RP-380. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1987.** 22 p.

Accounting for one of every six basic jobs, the forest products industry in Arkansas is the second largest component of the State's economic base. Furthermore, Arkansas is the most timber-dependent State in the South. Between 1970 and 1980, employment increased in the paper and allied products segment but decreased in the wood furniture and the lumber and wood products segments. Arkansas was one of two Southern States that had a smaller share of the Nation's employment in the forest products industry in 1980 than in 1970. This trend resulted partially from a shakeout of the southern pine plywood industry.

Keywords: Forest products industries, economics (forest products industries), employment (forest products industries), Arkansas.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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